EURO 2021

Program

All times are Athens time (EEST / UTC + 3 hours)

January 29, 2022

TECHNICAL PROGRAM

Sunday, 17:30-19:00

■ SF-01

Sunday, 17:30-19:00 - Bulding A, Amphitheatre

Opening Session

Stream: Opening and Closing
Plenary session
Chair: *Nikolaos Matsatsinis*
Chair: *Rudolf Vetschera*

1 - **Opening Session**
Rudolf Vetschera, Nikolaos Matsatsinis

Opening Session

Monday, 8:30-10:00

■ MA-01

Monday, 8:30-10:00 - Bulding A, Amphitheatre

Mathematical Models in Macro- and Microeconomics 1

Stream: Mathematical Models in Macro- and Microeconomics
Invited session
Chair: *Alexander Vasin*
Chair: *Michal Cerny*

1 - The calibration of ORDCs for a scarcity pricing mechanism in Belgium
Jacques Cartuvyels

The rise of renewable has lowered the profitability of the flexible thermic generators by pushing them out of the merit order. This non-friendly environment for investment put in the spotlight the crucial need for an adequate and fair price signal to remunerate flexibility. Scarcity pricing was introduced to cope with that lack of investment incentives by better rewarding the flexible assets. The mechanism is based on an Operating Reserve Demand Curve (ORDC) and takes the form of an adder that uplifts the price of energy when reserve is scarce in the system. By simulating an "idealized" real-time operation, we compare the incentives brought by different shapes of ORDC and the impact of those incentives on the total operating cost of the market. This total operating cost includes the production cost as well as the cost of shedding load. A balance needs to be found between wider ORDC that incur higher fixed cost due to their conservative procurement of reserve and narrower ORDC that are more exposed to shortage cost because of their lower procurement or balancing capacity. Results have shown that the cost differential was minimal between the different variants with a mean cost difference of around 0.5%. The reference scenario has displayed average adders between 3.7 euro/MWh and 4.8 euro/MWh with significant differences in the quality of the signals. Conservative ORDCs have produced higher mean adders that are less dependent on extreme periods with very high adders.

2 - On a Competitive Selection Problem with Recall
Dana Pizarro, Jérôme Renault, Fabien Gensbittel

We consider the problem in which N items arrive to a market sequentially over time, where a set of agents compete to choose the best possible item. When an agent selects an item, he leaves the market and obtains a payoff given by the value of the item, which is represented by a random variable following a known distribution. Agents observe the value of each item upon its arrival. When it is only allowed to take the item at the time it appears-and no latter-, this problem is an example of the classical Optimal Stopping Theory. However, this situation seems to be unrealistic for several applications where in fact it is possible to choose one option that appeared previously, if it is still available. This motivated us to study the latter problem, which we call competitive selection problem with recall. We described the game induced by it as a sequential game with imperfect information and we characterize the set of subgame perfect Nash equilibrium of the game. We also address the question of how much better is to have the power of get any available item compared to the take-it-or-leave-it fashion and we compared the sum of the expected payoff of the agents with the social optimum, obtaining bounds for what is known in the literature as Price of Anarchy and Price of Stability of the game.

3 - Combinatorial Auctions and Discrete Optimization: Desk bidding during a pandemic
Max Buckley

Owing to the global pandemic, many companies moved to a pure telecommuting business model. Between the various national lockdowns many of these same companies instituted a gradual rollback scheme, allowing their employees to return to the office in a limited fashion. This return was typically optional and not all employees participated. In this paper we explore various methods for approaching the problem of 'allocating office space to those who wish to make use of it in the fairest fashion possible while still respecting all the restrictions in place to protect the health and safety of all those involved'. In this paper we contrast two major approaches to the problem: a larger discrete optimization based approach versus a more dynamic combinatorial auction based approach. We also discuss some of the implications of these proposed solutions and the value of the data that emerges from them in facilitating future floor planning.

■ MA-02

Monday, 8:30-10:00 - Bulding A, Room A5

Power system economics

Stream: Economics and game theory (contributed)
Contributed session
Chair: *Anthony Papavasiliou*

1 - Firming Renewable Power with Demand Response: An End-to-end Aggregator Business Model
Shmuel Oren, Clay Campaigne

We consider an institutional framework in which Variable Energy Resources (VER) face market imbalance prices, incentivizing them to produce higher-value energy subject to less adverse uncertainty. In this setting, we consider an "aggregator" that owns the production rights to a VER's output and forms a "virtual power plant" (VPP) consisting of the VER and a portfolio of service curtailment contracts with a population of demand response (DR) participants whose "fuse" capacity can be reduced according to a pre-specified probability distribution. The aggregator bids day ahead VPP offers into the wholesale market, and is able to offset imbalances between the cleared day-ahead bid and the realized VER production by curtailing DR participants' consumption according to the signed contracts. We consider the optimization of the aggregator's end-to-end problem: designing the menu of DR service contracts using contract theory, bidding into the wholesale market, and dispatching DR consistently with the contractual agreements. We do this in a setting in which wholesale market prices, VER output, and participant demand are all stochastic, and possibly correlated.

2 - Integration of European balancing markets for electricity - dealing with local transmission constraints in a zonal market design
Mette Bjørndal

In Europe, electricity day-ahead and intraday markets are already well integrated, with a single price coupling algorithm to calculate electricity prices across Europe. At the present, the integration of balancing markets is advancing rapidly, with new trading platforms for activation of balancing energy being launched in the coming years. These trading platforms follow the design of the day-ahead and intraday markets, in that the physical networks are poorly represented, such that the cleared bids can lead to severe internal congestions within the zones, only a short time before delivery. We discuss how the Norwegian system operator can bid to the MARI platform for tertiary reserve activation, such that the physical network constraints of the control area are respected.

3 - An analysis of flow-based market coupling from a long-term perspective
Anthony Papavasiliou, Quentin Lété, Yves Smeers

The energy transition requires considerable investment in various technologies located throughout Europe. Except for remaining subsidies to particular technologies that are progressively dismantled, this investment process is meant to be driven by market forces. This means that investors will invest when and where their capacities are profitable. In this work, we analyze the impact of the zonal capacity allocation methodology used in Europe on investment. In particular, we show that the classical result of equivalence between centralized and decentralized capacity expansion, that is easily extended to transmission-constrained nodal markets and certain types of zonal markets, does not hold with the current methodology. We present a model of the decentralized capacity expansion problem in a zonal market with flow-based market coupling as a generalized Nash equilibrium and compare its results with other capacity allocation policies on a realistic instance of the Central Western Europe network.

■ MA-03

Monday, 8:30-10:00 - Bulding A, Room 3A

Sustainable Supply Chains (on-site)

Stream: Sustainable Supply Chains
Invited session
Chair: *Efthymios Katsoras*

1 - Designing sustainable supply chains
Petr Fiala, Renata Majovska

Sustainability in supply chain management has become a highly relevant topic for researchers and practitioners. The goal of supply chain sustainability is to create, protect and increase long-term environmental, social and economic value for all stakeholders involved in the marketing of products and services. Sustainable supply chains are modeled as multi-agent network systems that are evaluated according to multiple criteria. Multi-criteria decision making and game theory are a natural choice for effective design in such a situation with multiple agents with multiple criteria, where the outcome depends on the choice of each agent. Multi-criteria analysis is useful for assessing the sustainability of supply chains. Game theory has become a useful tool in designing supply chains with multiple agents, often with conflicting goals. The paper proposes several specific multiple criteria and game theory tools. De Novo multiple criteria approach was adapted for supply chain analysis. The approach is based on reformulating the problem with given resource prices and given budget. Biform games combine the non-cooperative and cooperative approaches of traditional game theory and are promising for analyzing the behavior of agents in supply chains.

2 - A dynamic analysis for closed-loop supply chains under the effect of Covid-19 pandemic
Efthymios Katsoras, Patroklos Georgiadis

Supply chains (SCs) is one of the most affected sectors by the COVID-19 pandemic, mainly in terms of significant consequences on profitability. For a SC, COVID-19 can be classified as a disaster event-that is a risk source of unknown - unknowns where it is rather difficult to quantify the likelihood of occurrence and, to establish effective mitigation strategies for a sustainable management of resources. The latter faces an increased level of complexity in the case of closed-loop supply chains (CLSCs). However,possible scenarios can be examined by means of models, which describe the interactions between different actors and functions in forward and reverse channels. In case of unknown-unknown effects, these interactions are rather non-linear.Moreover, the efficiency of the models is directly dependent on their ability to be based on a feedback structure of employing a dynamic analysis with adaptive control mechanisms and time delays. By considering that CLSCs are vulnerable systems under threats, we provide a system dynamics-based analysis of the COVID-19 effects on CLSCs operations. We study the response of the system through the dynamics at manufacturer level, by providing control mechanisms for resilient CLSCs under disaster effects. Under different scenario settings for the manufacturer and alternative risk mitigation policies, we provide a long-term dynamic analysis which reveals policy suggestions based on a balanced trade-off between profit and resource utilization.

■ MA-04

Monday, 8:30-10:00 - Bulding A, Room 3B

Emerging Applications in Management Science I

Stream: Emerging Applications in Portfolio Selection and Management Science
Invited session
Chair: *Felipe Feijoo*

1 - Using deep learning to predict public transport ridership during disruptions
Menno Yap, Oded Cats

Public transport (PT) networks can be subject to maintenance works, resulting in disruptions of PT supply for passengers which can last multiple days, weeks or even months. To better understand the impact of such closures on passengers (mode choice) and PT provider (revenue impact), it is important to be able to predict how PT ridership is affected during a closure and how PT demand recovers once the service is restored.

When predicting PT ridership, the vast majority of PT agencies relies on simple, aggregate models using travel time or cost elasticities. In this study, we develop a disaggregate prediction model with which we predict for individual passengers whether they continue using PT during and after the closure, resulting in more accurate predictions.

For this purpose, we develop and test several machine learning models, ranging from relatively simple classifiers (Naive Bayes, Random Forest) to more advanced deep learning approaches such as Convolutional Neural Networks. We use 12 weeks of individual passenger smart card data from Amsterdam, consisting of empirical data before, during and after a large closure in the Amsterdam PT network. Based on network properties (travel time, transfers), socio-demographic characteristics of the area (such as average income, car ownership) and passenger type (frequent vs. infrequent traveller, card type, time of day) we train and validate our model. Based on this, we train and validate our model to predict PT ridership.

2 - Multi-Compartment Truck and Trailer Routing Problem: model and solution methods
Laura Davila Pena, David R Penas, Balbina Casas-Méndez

Vehicle routing problems admit different variants depending on the clients' needs. One of them is the truck and trailer routing problem, TTRP, where a fleet of trucks and trailers serves a set of customers such that when the trailer is not able to reach a customer, they are attended only by the truck. This work proposes a novel mixed-integer linear programming approach to combine the TTRP with product compartmentalization, which we call the multi-compartment truck and trailer routing problem (MC-TTRP). The combination of these two features is motivated by the needs of a Spanish agricultural cooperative that produces feed for cattle. Given that MC-TTRPs have an NP-hard complexity, optimal solving via exact methods for large size instances is computationally expensive. Thus, the use of approximated techniques, such as heuristics, becomes necessary in order to obtain quality solutions in a reasonable time. Therefore, we present a new heuristic algorithm for the MC-TTRP. Our proposal consists of a two-stage approach: the first phase iteratively builds an initial solution, based on the savings method of Clarke and Wright, and then the second phase aims to refine the solution. We carried out a computational study on new 21 test problems adapted from those in preexisting literature. The results obtained prove the effectiveness of our algorithm, which always finds a feasible solution. Furthermore, this heuristic is applied to the aforementioned real example of the cooperative.

3 - An MIP Model with Endogenous Capacity Investment for Energy Transition Pathways - Interrelation Between Power-to-X, demand Response and Market Coupling
Felipe Feijoo

Climate change and global warming are among the main issues that society faces nowadays. It is known that CO_2 and GHG emissions play a major role in this context. To limit the increase in temperature, several countries developed targets to reduce their emissions levels, particularly from the energy and transport sectors. To achieve these targets, energy systems are being transformed with increased shares of renewable energy. Large deployments of renewable sources provide new challenges. Particularly, their high variability creates large uncertainties to the energy system regulators to guarantee security of supply at affordable prices. Therefore, new approaches must be considered to reduce the uncertainty associated with renewable energy. Power-to-X and demand response technologies, which provide high degree of flexibility to energy systems, could be a viable solution. We propose a MIP to model systems with consideration of Power-to-X and demand response technologies. The model represents the unit-commitment of a system minimizing the total operational cost. Additionally, we extend the proposed model to account for endogenous capacity investment decisions in power, heat, and storage technologies. The model is applied to the Croatian Energy system. We show that Power-to-X indeed provides the required flexibility to the new capacity additions of variable renewable sources, reaching systems with lower levels of excess of energy production.

■ MA-06

Monday, 8:30-10:00 - Building Δ, Room Δ103

MILP algorithms for routing problems I

Stream: Mixed Integer Linear Programming
Invited session
Chair: *Roel Leus*

1 - Exact algorithms for budgeted prize-collecting covering subgraph problems
Nicola Morandi, Roel Leus, Hande Yaman

We introduce a class of budgeted prize-collecting covering subgraph problems. For an input graph with prizes on the vertices and costs on the edges, the aim of these problems is to find a connected subgraph such that the cost of its edges does not exceed a given budget and its collected prize is maximum. A vertex prize is collected when the vertex is visited, but the price can also be partially collected if the vertex is covered, where an unvisited vertex is covered by a visited one if the latter belongs to the former's neighbourhood. A capacity limit is imposed on the number of vertices that can be covered by the same visited vertex. Potential application areas include network design and intermodal transportation. We develop a branch-and-cut framework and a Benders decomposition for the exact solution of the problems in this class. We validate our algorithmic frameworks for the cases where the subgraph is a tour and a tree, and for these two cases we also identify novel symmetry-breaking inequalities.

2 - A branch-and-price algorithm for the multi-depot multi-trip vehicle routing problems with time windows
Kubra Sahin, Hande Yaman

The aim of this study is to propose an exact algorithm for the Multi-depot multi-trip vehicle routing problems with time windows. Multi-trip vehicle routing problems (MTVRPs), in which vehicles are allowed to perform several trips in a workday, have received more attention in the last years due to the new challenges in city logistics and the increase in awareness about environmental issues that pushes companies to change their delivery policies towards a more sustainable way. Although several variants of the MTVRP have been investigated in the literature, to the best of our knowledge, multi-depot variant has not been studied yet. We formulate this problem with workday, i.e., a sequence of consecutive trips, variables and develop a branch-and-price algorithm that exhibits an enhanced performance by a new heuristic algorithm based on the reduction in the graph size.

3 - A novel sub-problem of the Vehicle Routing Problem with Time Windows
Philipp Armbrust, Kerstin Maier, Christian Truden

The Vehicle Routing Problem with Time Windows (VRPTW) asks for the optimal set of routes to be performed by a fleet of vehicles to serve a set of customers within their assigned time windows. In this work, we propose to solve the sub-problem constituted by optimizing only a selected time window of the VRPTW while all other time windows are "frozen". We call this problem the Single Time Window Vehicle Routing Problem (STWVRP). It is necessary to assume that several customers are assigned to the same time window, i.e., the number of customers is much larger than the number of time windows. This rather mild assumption easily holds for most applications of the VRPTW that are concerned with transportation and home delivery services. With the help of a Mixed-Integer Linear Program, we give an exact problem description of the STWVRP. Further, we apply this exact formulation within a matheuristic for the VRPTW. Finally, we provide an extensive computational study.

■ MA-21

Monday, 8:30-10:00 - Virtual Room 21

Exploring individual differences and cognitive biases

Stream: Descriptive and prescriptive behavioural OR studies
Invited session
Chair: *Ayşegül Engin*

1 - Using visualisation for activating the adequate thinking mode when making stock-flow related decisions
Michael Leyer, Ayşegül Engin, Jürgen Strohhecker

Systematic decision errors for individuals usually arise on one hand due the necessity to exhaust the cognitive resources to project a depicted decision task to a mental model and on the other hand using the adequate thinking mode to provide a solution for the task. We argue that with a constant task complexity, a matching task representation to the decision maker's cognitive style and to the task characteristics can reduce cognitive requirements. This matching is dependent on the requirements of the task and the tendency of individuals to use either their slow, analytic or their fast, intuitive system when faced with a decision as described by dual-processing theories, e.g. cognitive-experiential theory. Results from experiments with static tasks rooted in cognitive fit theory show that a promising idea is to use structural visualization to help individuals in achieving the match between task requirements and adequate thinking mode. When confronted with a simple dynamic task (three stocks and three flows), two types of structural visualization containing the logic of stock-flow are compared to an alphabetical order of variables as control group. We conduct an experiment with participants to demonstrate how structural visualisation can activate an analytical thinking mode which is necessary to solve a simple dynamic task. The results are contributing to our understanding how decision making can be improved by activating the adequate thinking mode using visualisation.

2 - Choice blindness detection as an indicator of stable risk preference for public policy?
Lisa Scholten

The ability to identify the degree to which stated risk preferences as inferred from choice trials are stable or artefacts of behavioural influences remains a challenge in preference elicitation for public policy. A randomized controlled online experiment is presented in which I studied whether common behavioural predictors of risk preference instability and choice blindness coincide for 5 wastewater policy outcome domains. In psychology, 'choice blindness' refers to someone's failure to detect a sleight of hand between their selected and unselected choice option, where choice manipulation detection indicates preferences that are strongly held and likely more stable. Whereas participants' risk preferences were moderately stable across elicitation trials, the stimuli used (icon array vs. numeric) split the population into risk-seeking vs risk-averse. Moreover, ca. 3/4 of the 330 participants were choice blind and those who weren't detected only 1/10th of all manipulations. Of several task-, domain-, and individual-level variables tested, the only significant common predictors were risk numeracy and gamble distinctness. These results defy the idea that risk preferences as inferred from choices on elicitation gambles measure stable preferences. The identified predictors indicate directions for closer study of the links between cognitive processing, preference, and choice that are important for OR researchers who aim to elicit risk preferences to inform public policy.

3 - Anchoring in interactive Goal Programming: A behavioral experiment

Maura Hunt, Manuel López-Ibáñez, Paul Warren, George Farmer

In Multicriteria Decision-Making (MCDM), some methods, such as interactive goal programming (iGP), alternate between eliciting preferences from a decision-maker (DM) and using those preferences to find a solution. Humans are a crucial component of this interactive system, yet the impact of cognitive factors on outcomes is often overlooked. Decision-making research has revealed many cognitive biases that affect behavior in estimation and choice tasks. One such bias is anchoring, where estimates of a quantity are robustly biased towards a given value. For example, when determining Everest's height, DMs remain significantly close to the experimenter's initial value, even if that value is meaningless. Understandably, such biases could impact more complex tasks like those in MCDM; however, few experiments have considered anchoring in this context.

We present a behavioral experiment (N = 40 DMs) investigating anchoring in iGP for two simple decision problems, each involving two conflicting criteria. In addition, we measured the classical anchoring effect from the psychological estimation tasks. Our analysis suggests that where a DM begins their interaction significantly influences where they end, which persists when accounting for preferences. However, we found no evidence that classical anchoring was related to the effect observed in iGP. These findings support the idea that the initial points influence DMs, making them critical for a successful iGP application.

4 - Decision-maker characteristics and the ratio bias: What drives preferences for ratios of high vs. low numbers?

Ayşegül Engin, Rudolf Vetschera, David Bourdin

The Ratio Bias - frequently studied in literature- refers to the fact that decision makers tend to overestimate probabilities that are specified as ratios of large numbers in comparison to the same probabilities represented by a ratio of smaller numbers (e.g., 9:100 vs. 1:10). In this paper, we study such deviations in a more general setting that includes the standard ratio bias as well as systematic deviations in favor of ratios of low numbers, irrational indifference between two ratios, and the inability to choose. We explore the influence of problem characteristics such as probability levels involved and decision-maker characteristics such as their reliance on the rational/experiential system and their risk literacy on the occurrence of systematic deviations in either direction. Our findings indicate a strong impact of risk literacy on the susceptibility to all such phenomena, but also show that different additional factors are responsible for deviations in different directions. The predominant direction of deviations is also strongly influenced by the actual probability involved, with low probabilities leading to a ratio bias and high probabilities to a bias in the opposite direction. To further clarify the role of experiential vs. rational systems in the occurrence of these biases, we consider response times, where we find that answers that interpret probabilities correctly are produced faster than deviating answers.

■ MA-22

Monday, 8:30-10:00 - Virtual Room 22

Conic optimization and applications

Stream: Conic Optimization and Related Topics
Invited session
Chair: *Lucas Létocart*
Chair: *Paula Amaral*

1 - A computational study of solution approaches for computing the Restricted Isometry Property using a mixed-integer SDP

Frederic Matter, Marc Pfetsch

The Restricted Isometry Property (RIP) is an important tool in compressed sensing, since it states a sufficient condition for when it is possible to recover a sparse solution using a tractable linear program instead of a nonconvex program. Moreover, the RIP is closely connected to sparse PCA, which is also of considerable interest in data analysis. Testing whether the RIP is satisfied can be formulated as a mixed-integer semidefinite program (MISDP), which can be solved using a branch-and-bound algorithm, where in each node an SDP is solved. It is also possible to use an outer-approximation of the SDP cone using eigenvector cuts and solve the resulting LP relaxation in each node of the branch-and-bound algorithm. After introducing the MISDP formulation for computing the RIP, we evaluate its performance computationally using the MISDP solver SCIP-SDP, which implements both variants of branch-and-bound. Additionally, we present several ideas to improve the MISDP formulation and the solution process such as using valid inequalities originating from sparse PCA or the sparsification of the eigenvector cuts and discuss their impact. This is joint work with Marc Pfetsch.

2 - Identification of Best Discrimination Surface by Mixed-Integer Semi-Definite Programming for Support Vector Machine

Katsuhiro Tanaka, Rei Yamamoto

This paper proposes two improvements to the support vector machine (SVM): (i) extension to a semi-positive definite quadratic surface, which improves the discrimination accuracy; (ii) addition of a variable selection constraint. However, this model is formulated as a mixed-integer semi-definite programming (MISDP) problem, and it cannot be solved easily. Therefore, we propose a heuristic algorithm for solving the MISDP problem efficiently and show its effectiveness by using corporate bankruptcy data.

3 - Exploiting Partial Correlations in Distributionally Robust Optimization

Divya Padmanabhan, Karthik Natarajan, Karthyek Murthy

In this paper, we identify partial correlation information structures that allow for simpler reformulations in evaluating the maximum expected value of mixed integer linear programs with random objective coefficients. To this end, assuming only the knowledge of the mean and the covariance matrix entries restricted to block-diagonal patterns, we develop a reduced semidefinite programming formulation, the complexity of solving which is related to characterizing a suitable projection of the convex hull of the set $(boldx, boldxboldx'): boldx in mathcalX$ where $mathcalX$ is the feasible region. In some cases, this lends itself to efficient representations that result in polynomial-time solvable instances, most notably for the distributionally robust appointment scheduling problem with random job durations as well as for computing tight bounds in the newsvendor problem, Project Evaluation and Review Technique (PERT) networks and linear assignment problems. To the best of our knowledge, this is the first example of a distributionally robust optimization formulation for appointment scheduling that permits a tight polynomial-time solvable semidefinite programming reformulation which explicitly captures partially known correlation information between uncertain processing times of the jobs to be scheduled. We also discuss extensions where the random coefficients are assumed to be non-negative and additional overlapping correlation information is available.

4 - Matrix generation for binary quadratically constrained quadratic problems
Lucas Létocart, Enrico Bettiol, Immanuel Bomze, Francesco Rinaldi, Emiliano Traversi

We consider binary quadratically constrained quadratic problems and propose a new approach to generate strong bounds. The new relaxation is based on the Boolean Quadric Polytope and is solved via a Dantzig-Wolfe Reformulation in matrix space. For block-decomposable problems, we extend the relaxation and if overlapping size of blocks is at most two, we establish equivalence to the one based on the Boolean Quadric Polytope. We conjecture that equivalence holds for any block structure with a chordal sparsity graph. Numerical experiments show that the proposed approach yields very good bounds in reasonable time, in comparison with a state-of-the-art solver.

■ MA-23

Monday, 8:30-10:00 - Virtual Room 23

Recent Progresses in Mixed-Integer Derivative-free Optimization

Stream: Derivative-free Optimization
Invited session
Chair: *Nikolaos Ploskas*
Chair: *Ana Luisa Custodio*

1 - Bayesian Optimization of Neural Network Hyperparameters Using Gaussian Processes
Christian Milano, Umberto Iemma, Andrea Serani, Matteo Diez

Data science has emerged as a cutting-edge research field that develops and applies rigorous methods and algorithms to gain knowledge from data. Among other methods, neural networks have proven to be effective in modelling datasets from experiments or simulations, thus reducing the computational cost of design performance assessment and optimization procedures or gain insights of complex physical phenomena. The performance of the neural network in approximating the desired dataset depends on its internal hyperparameters. In this work the optimization of the hyperparameters of a neural network is presented for improving the representation of aeroacoustic datasets from experiments and simulations. The neural network is characterized by 5 hyperparameters, both integer and continuous. A Gaussian process metamodel is used to accurately approximate the reconstruction error of the datasets while reducing the number of hyperparameters sets that need to be tested. The reconstruction error is computed as the normalized mean squared error in a k-fold cross-validation procedure. The optimization of both the integer and continuous hyperparameters is finally performed using a deterministic version of the derivative-free particle swarm optimization algorithm. The proposed methodology is compared with a random-search approach for the hyperparameter optimization.

2 - Towards a Global Derivative-free Trust-region Method for Mixed Continuous and Discrete Problems
Delphine Sinoquet, Thi Thoi Tran, Sébastien Da Veiga, Marcel Mongeau

This work is motivated by optimization applications based on complex and expensive black-box simulators. Our goal is thus to achieve the best improvement in function minimization with the fewest possible simulations. We propose a new global optimization method that is an extension of a local Derivative-Free Optimization Trust-region method for mixed continuous and discrete problems (DFOb). The latter method is based on two main steps: successive continuous quadratic sub-problems and mixed binary quadratic sub-problems that both rely on interpolation models defined for mixed variables, valid within an adaptive trust region. To force exploration for binary variables, "no-good cut" constraints are added to force the algorithm to explore outside of the previously explored regions.

Our approach to global optimization is to use our local solver DFOb coupled with a restart procedure that resets the trust region size and enables an enrichment of the simulation dataset for exploration whenever the algorithm no longer makes sufficient progress. Precisely, our strategy to pick these new simulations relies on a novel design of experiment method that uses kernel-embedding of probability distributions adapted to mixed variables, enabling to take into account any available prior information from the type of problem we address. Several applications of the proposed method will be presented for a benchmark of functions.

3 - A Computational Comparison of Mixed-integer Derivative-free Optimization Solvers in an Adaptive Sampling Surrogate Modeling Framework
Emmanouil Karantoumanis, Nikolaos Ploskas

Derivative-free optimization (DFO) has recently received a lot of attention. Expensive black-box optimization problems are becoming more and more common in science and engineering. In this work, we have implemented an adaptive sampling surrogate model framework for solving black-box optimization problems. Initially, a sampling method is utilized to determine initial sampling points. Then, a surrogate model is generated by ALAMO as an approximation model for the original objective function of the problem. The surrogate model is evaluated and if the termination criteria are not met, then a re-sampling strategy is executed. In this step, we utilized DFO solvers to re-sample new points and feed them back to ALAMO in order to generate an updated surrogate model. In this step, we utilize various DFO solvers in order to produce new sampling points. These DFO solvers need to take into account already evaluated points. There are only a few DFO solvers that utilize already evaluated points and can also handle integer variables. The new sampling points are used by the surrogate framework in an adaptive procedure until the termination criteria are met. In this work, we compare various DFO solvers (MATLAB's surrogateopt, MISO, Nevergrad, SNOBFIT, and ZOOpt) than can be utilized in such an adaptive framework. We present extensive computational results on pure and mixed-integer optimization problems.

4 - A Computational Comparison of Mixed-integer Derivative-free Optimization Algorithms
Nikolaos Ploskas, Nikolaos Sahinidis

A growing number of applications in science and engineering deal with the solution of black-box optimization problems, where derivative information of the objective function is unavailable, unreliable or impractical to obtain. The algorithms that are utilized to solve this type of problems are called derivative-free algorithms. Although the algorithmic and theoretical aspects of derivative-free algorithms have significantly progressed over the past two decade, derivative-free algorithms dealing with discrete variables have not yet attracted much attention. In this work, we review recent advances on solving bound-constrained mixed-integer derivative-free optimization problems and present a computational comparison of existing implementations on a large collection of test problems. Thirteen bound constrained mixed-integer derivative-free optimization solvers are compared using a test set of 267 problems. The test bed includes pure integer and mixed-integer problems. Computational results show that the ability of all these solvers to obtain good solutions diminishes with increasing problem size, but the solvers evaluated collectively found optimal solutions for 93% of the problems in our test set. The open-source solvers MISO and NOMAD were the best performers among all solvers tested. MISO outperformed all other solvers on large and binary problems, while NOMAD was the best performer on mixed-integer, non-binary discrete, small, and medium-sized problems.

■ MA-24

Monday, 8:30-10:00 - Virtual Room 24

Recent Results in Global Optimization 1

Stream: Global Optimization
Invited session
Chair: *Mario Alberto Mendoza Villalba*

1 - Duality for nonconvex optimization problems with abstract convex functions

Monika Syga, Ewa Bednarczuk

We investigate duality for nonconvex optimization problems. To this aim we use the abstract convexity theory and minimax theorem for abstract convex functions. We provide conditions for zero duality gap and strong duality. Among the classes of functions, to which our duality results can be applied, are prox-bounded functions, DC functions, weakly convex functions and paraconvex functions. We put particular stress on weakly convex functions which have numerous applications in optimization problems arising in signal and image processing. We provide conditions for zero duality gap and strong duality.

2 - Lipschitz global optimization

Yaroslav Sergeyev, Dmitri Kvasov, Marat Mukhametzhanov, Maria Chiara Nasso

LIPSCHITZ GLOBAL OPTIMIZATION

Y.D. Sergeyev*', D.E. Kvasov*', M.S. Mukhametzhanov*', M.C. Nasso*

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Global optimization is a thriving branch of applied mathematics and an extensive literature is dedicated to it. In this talk, the global optimization problem with a multidimensional function satisfying the Lipschitz condition over a hyperinterval with an unknown Lipschitz constant is considered. It is supposed that the objective function can be "black box", multiextremal, and non-differentiable. It is also assumed that evaluation of the objective function at a point is a time-consuming operation. Several algorithms proposed by the authors for solving this problem are discussed. They can be distinguished, for example, by the way of obtaining information about the Lipschitz constant and by the strategy of exploration of the search domain. Exploration techniques based on various adaptive partition strategies are analyzed.

Selected references

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3 - Escape Strategies Algorithm (ESSA), a new meta heuristic algorithm for global optimization problems, inspired in pre-predator interaction

Mario Alberto Mendoza Villalba, Jesus David Galarcio Noguera, Jorge Mario López Pereira

The challenge of improving optimization techniques remains, today more than ever, a subject of great importance in many fields of science and engineering. Because, every day more problems arising that require the use of various optimization methods, in addition, the complexity of the methods increases as systems become more complex, forcing it to solution techniques have to be increasingly efficient; that is way the development of new approximate methods (heuristics and metaheuristics) has becoming an important alternative in solving complex problems for its versatility, applicability and efficiency. Also, this paper proposes a new global optimization metaheuristic algorithm named ESCAPE STRATEGIES ALGORITHM (ESSA), inspired by the interaction between predator and prey, and how the preys try to evade to predator; which is tested in real functions, comparing with continuous encoding metaheuristics widely referenced in literature, getting (ESSA) an equal to or better performance in their solutions to a standard time on multiple test instances, besides equaling in standard score to the best comparison algorithms and overcoming them several of the most cited. In addition, the descriptive statistical annalyzis shows, in fact, ESSA is the algorithm that obtains best results in biggest quantity of test instances; evidencing a best performance in instances with greates number of variables.

■ MA-25

Monday, 8:30-10:00 - Virtual Room 25

Stochastic Optimization in Energy

Stream: Stochastic and Robust Optimization
Invited session
Chair: *Patrizia Beraldi*
Chair: *Francesca Maggioni*

1 - A two-stage stochastic programming approach for the long-term expansion co-planning of electricity and gas systems with bi-directional energy conversion

Giovanni Micheli, Maria Teresa Vespucci, Cinzia Puglisi, Alessia Cortazzi

The deployment of gas-fired power plants and Power-to-Gas plants increases the interconnection between electricity and gas systems and requires an integrated planning framework that could accurately consider this coupling. This contribution provides a comprehensive formulation for the expansion co-planning of integrated energy systems with high penetrations of intermittent renewable energy sources and bi-directional energy conversion. Since expansion plans are usually made for a long-term horizon, the system conditions are generally uncertain at the time the expansion plans are decided. In this work, we focus on the uncertainty of thermal power plants production costs and we define expansion decisions using a two-stage stochastic programming model, with the first stage representing the investment problem and the second stage being the operational problem. To keep the problem computationally tractable, we apply a clustering analysis on input data to select a set of representative days and we implement a multi-cut Benders Decomposition algorithm, decomposing the stochastic model both by year and by scenario. We then apply the proposed analysis to the Italian integrated electricity and gas system to evaluate the achievement by 2040 of sustainability goals set by the European Commission. Empirical results show how solar technology could play a key role in the achievement of these policy targets, being the main technology installed by the model.

2 - Day-ahead and intra-day co-optimization of a power unit under uncertainty

Adrien Le Franc, Michel De Lara

We consider renewable power units equipped with a battery and engaged in day-ahead load scheduling. In this context, the unit manager must submit a day-ahead power production profile prior to every operating day, and is engaged to deliver power accordingly. During the operating day, the unit manager is charged penalties if the delivered power differs from the submitted profile. First, we model the problem of computing the optimal production profile as a parametric multistage stochastic optimization problem. The production profile is modeled as a parameter which affects the value of the intra-day management of the power unit, where the photovoltaic production induces stochasticity. Second, we expose numerical methods to compute or approximate a subgradient of the value functions of the problem with respect to the parameter, and finally, we showcase applications in the context of the French non-interconnected power grid and benchmark our method against a Model Predictive Control approach.

3 - The Optimal Design and Operation of a Residential Prosumer System: A Stochastic Programming Approach
Patrizia Beraldi

The electricity market is undergoing a challenging transformation, slowly evolving from an electricity production system dominated by large centralized generating units to a system with an increasing amount of energy production from renewable energy sources and small power plants. In this new landscape, the figure of the consumer also changes. Domestic consumers are producing more and more energy, for example by installing solar panels on their roofs, installing a wind turbine on their property, or producing biogas from waste. This new trend of households to be both producers and consumers of energy is known as "prosumption" and is facilitated by technical developments such as battery systems, smart meters, and advanced business models that promote self-consumption through the technical design of electrical systems. This talk focuses on the optimal design and operation of a domestic energy system consisting of photovoltaic panels and storage devices. The uncertainty inherent in production from renewable sources and in the purchase price of electricity confers a stochastic nature to the problem under investigation. A stochastic programming formulation is defined and tested in real case studies. The numerical results show the effectiveness of the proposed approach in terms of cost savings and the relative advantage of using a stochastic programming approach compared to a deterministic formulation.

■ MA-27

Monday, 8:30-10:00 - Virtual Room 27

Prescriptive Analytics in Service Routing

Stream: Analytics in Service Management
Invited session
Chair: *Ninja Soeffker*

1 - Anticipatory Decision-Making for Dynamic Vehicle Routing with Stochastic Customer Requests
Ninja Soeffker, Marlin Wolf Ulmer, Dirk Christian Mattfeld

We consider a dynamic vehicle routing problem with stochastic customer requests. In this problem, some requests are known in advance (initial requests) and others arrive throughout the time horizon while several workers in vehicles already serve customer requests. Before the start of the time horizon, initial routes have to be constructed that contain all initial requests. In this work, we consider different options for this initial route construction. When a new request arrives, a decision has to be made about whether the request is served and by which vehicle it will be served. For an anticipatory decision-making with respect to both decisions, we apply a value function approximation approach. In this presentation, we analyze the impact of the initial route construction, the impact of the state features used as well as their interrelation.

2 - When to Reschedule Vehicles in Case of Disruptions
Martijn Koot, Martijn Mes, Maria Iacob

Rapid advancements in remote sensing technologies enable logistics companies to keep track of their fleet in (nearly) real-time. While fleet operators can evaluate the continuous stream of dynamic events in search for any harmful disruption already, more flexible and reliable operations can only be obtained if the track-and-trace services are made actionable by enhancing them with online rescheduling policies. In this research, we investigate the timing of re-optimizing the Vehicle Routing Problem with Time Windows (VRPTW) in response to dynamic events, especially once a disturbance affecting the vehicles' travel times is observed on route. Therefore, we first extract useful features from the fleet's continuous data streams to predict the severity of potential disturbances. Second, we construct, simulate, and evaluate multiple rescheduling policies to resolve all classified dynamic events. We illustrate this challenge by extending the well-known Solomon instances with a more realistic road network, as the decision complexity increases for real-life problems constrained by the physical infrastructure. Through simulation, we study how disturbances impact the VRPTW performance considering various disruption types, disruption frequencies, impact radii, severity levels, local network characteristics, and resolution times. Furthermore, we show how fleet operators could learn those rescheduling policies in advance to improve response times.

3 - Deep q-learning for same-day pickup and delivery problems
Florentin Hildebrandt, Marlin Wolf Ulmer

The demand for same-day pickup and delivery (e.g., restaurant meal delivery) has grown rapidly in recent years. This trend is further accelerated by the Covid-19 crisis, surpassing even the most generous growth estimations. Service providers must scale efficiently with increasing demand to stay ahead in a competitive market. One important step towards efficient operational planning is anticipatory assignment of orders to couriers. This is a difficult task for same-day pickup and delivery problems due to high uncertainty in future orders and delivery processes. We propose a deep dueling q-network to learn the future value of assigning an order to a specific vehicle in the fleet. The q-network draws from full state information including the complete tentative routing of the fleet. In our experiments, we test our method for a restaurant meal delivery problem based on data from a meal delivery platform located in Iowa city. We show that our reinforcement learning policy strongly improves upon a myopic assignment policy commonly used in practice.

■ MA-28

Monday, 8:30-10:00 - Virtual Room 28

Data Science and Analytics - Methodology III

Stream: Data Science and Analytics (contributed)
Contributed session
Chair: *Maeng Daeju*

1 - Time Series Fault Detection and Diagnosis Using A Two-Stage Attention-Based Recurrent Neural Network in Copper Refining Manufacturing
Jae-Jin Yoo, Jun-Geol Baek, Yunsung Moon, Kyesun Park

The data collected during the manufacturing process is a very large amount of multivariate time series data, which can be used for data-driven time series fault detection and diagnosis. However, in order to successfully construct a fault detection model of sequential data, input features must be successfully extracted even in a situation where there is a large number of variables, and temporal dependencies also must be successfully captured even with long-range of time. In this paper, we propose a two-stage attention-based recurrent neural network(TA-RNN) that allows fault detection and diagnosis using two attention stage in the long short-term memory (LSTM) structures. The attention mechanism used in the first stage refers to the previous LSTM hidden state and weight important input features at each time step. In the second stage, we used self-attention machanism to weight important time points in the sequential data. Experimental results using real-world data from the copper smelting process demonstrate our model outperformed other time-series classification models with less training time. Moreover, using the attention score derived from each attention stage, we were able to identify variables and the time that significantly affect the fault.

2 - Instance-dependent cost-sensitive learning: Do we really need it?
Toon Vanderschueren, Bart Baesens, Wouter Verbeke, Tim Verdonck

Traditionally, classification algorithms aim to minimize the number of errors. However, this approach can lead to sub-optimal results for many (business) applications where the actual goal is to minimize the total cost of errors, not their number. For example, in customer churn, the algorithm's predictions should be especially reliable when dealing with highly valuable customers, even at the cost of misclassifying churners with insignificant value. Cost-sensitive learning aims to address this issue by incorporating costs in the learning algorithm. Recently, a number of cost-sensitive classifiers have been suggested that deal with the case of instance-dependent costs (a.k.a. observation- or record-dependent costs). This work presents the results of a benchmarking experiment, comparing the performance of instance- and class-dependent cost-sensitive, as well as cost-insensitive learning methods. Using real-life data from a range of application areas, we analyze the effects of incorporating costs at the instance-level, as well as the influence of thresholding and regularization, on the performance of the resulting model, which is evaluated both using cost-sensitive and cost-insensitive performance measures.

3 - Clustering-based representative multivariate time series creation

Gabor Tamas, Elisabeth Zehendner, David Schmaranzer, Emel Arikan, Gerald Reiner

The potential impact of descriptive analytics is often underestimated, although historical datasets are continually growing as businesses become more and more complex. Therefore, recognizing and treating data as an asset is crucial for almost any company's success. However, without having the right tools for the analysis, there is a risk of missing otherwise promising opportunities. What is even worse, the results might also be misleading.

In the presented research, we build a model to create representative multivariate time series based on historical data. Our aim is to define time periods in which the historical time series show similar behaviour. Clustering is used for the categorization of input data samples along the temporal dimension. As an output, the model produces representative time series for each cluster.

The presented method's applicability is demonstrated utilizing data from a major logistics and postal services provider. Various clustering techniques, including the widely used K-means and the emerging HDBSCAN, are compared by exploring how the method selection influences the obtained results. Our analysis indicates that the appropriate combination of unsupervised machine learning algorithms is a useful tool for creating representative parcel flow patterns. These patterns will enable better parcel distribution network planning both on the strategic and the tactical level.

4 - Masked-CNN : CNN-based Class Probability Correction using Mask Image

Maeng Daeju, Jun-Geol Baek

In image classification problems in the field of computer vision, Convolutional Neural Network (CNN) is being utilized as the most outstanding performance tool. Recently, a Class Activation map-based visual explanation method is widely used to describe CNN-predicted results and find important regions in images. In this paper, we develop a masked-CNN that can improve image classification performance through class probability correction utilizing mask images. Mask filters are generated by a combination of Class Activation maps of each class and contain information about the important regions of the image. Mask images provide additional information for image classification. We pass this mask image through an existing CNN model to generate a correction value, we correct it to the class probability of the input image. The final prediction is performed through corrected class probabilities. The proposed method can improve the classification performance of existing CNN models without any change in model architecture or additional learning. Experiments show that image classification performance after class probability correction is better than existing models. We will also observe the effectiveness of the correction according to the generation method of class activation map. We use ImageNet(ILSVRC2012) data, and the classification performance is verified by various CNN models(VGG, ResNet, etc.).

■ MA-29

Monday, 8:30-10:00 - Virtual Room 29

AHP/ANP Applications

Stream: AHP/ANP
Invited session
Chair: *Ozay Ozaydin*

1 - An ANP Model for Evaluating Architectural Design Projects in Architectural Education

Ozay Ozaydin, Nil Akdede

Architectural design is essential for architecture education. Despite its significance, the literature frequently presents the evaluation of these design projects as one of the vital problems due to the difficulty in identifying and determining the design criteria and their interrelations. This study aims not only to present a comprehensive criteria tree but also to display the significance of relations among criteria. To deliver on these, a three-stepped methodology is adopted. First, a comprehensive literature survey is conducted to determine the initial criteria. Second, the Delphi technique is adopted to validate and improve the proposed criteria from the first stage. Also, in this stage, the relationship between the criteria are revealed. Finally, ANP (Analytic Network Process) as an MCDM method, is implemented to evaluate the architectural design projects based on the criteria determined in the previous phases. Top-level initial criteria include form, function and durability, also the weighing will differentiate urban and rural projects. The results show that the relations between architectural design assessment criteria are significant. Ignoring these relations will directly affect the result of the assessment. Therefore, besides implementing the method in the evaluation of architectural design projects in architecture education, it can also be applicable for evaluating architectural design competitions.

2 - Evaluating Hi-Fi audio systems in terms of sound quality with DEMATEL-Based Analytic Network Process and PROMETHEE

Ozan Apaydın, Zerrin AladaĞ, Selçuk Cüneyt Altinkaya

The quality of sound reproduction depends on all the elements in the chain including source, amplifier(s), loudspeakers, connectors and cables. Available metrics are not sufficient for determining sound quality and do not give an idea of how a system sounds. On the other hand, subjective evaluation of Hi-Fi audio systems is an arduous and time-consuming task. Therefore, insubstantial rating of these systems is a common approach on this market. This research employs scientific methods such as DEMATEL-Based Analytic Network Process (DANP) and PROMETHEE to compare and assess Hi-Fi audio systems. An experimental study is designed and conducted to observe and collect data required for subjective evaluation. Two new preference functions of PROMETHEE are also put into practice. The results show that Hi-Fi audio systems can be ranked sensitively using multi-criteria decision making methods.

3 - Analysis, Prioritization and Strategic Planning of Flood Mitigation Projects using AHP in a GIS Environment

Marina Aidinidou, Andreas Georgiou

Floods, undoubtedly constitute a major global issue and cause significant consequences in the operations of contemporary cities. In addition, the management of sustainable water resources requires a well-defined and validated decision-making framework in order to facilitate the implementation of available measures. This study establishes a set of risk criteria concerning the comprehensive urban flood risk assessment and investigates the criteria changes on different weighted sets, in both value and spatial distribution. The model, based on spatial data and expert opinions, is used to assess flood vulnerability and prioritize mitigation projects in the study area. Based on the research objectives, the data availability, and the current technology, vulnerability is chosen to be expressed as a function of 18 multidimensional factors which are categorized under the three sustainability pillars: the environment, the society and the economy. Then Analytical Hierarchy Process (AHP), is coupled with a spatial database environment, generated in a Geographic Information Systems (GIS) software. As a result, the outcome of the aforementioned process is included in a vulnerability map which can be used in structuring a hierarchy of the ranked future flood mitigation projects. Finally, the model is used to conduct spatial sensitivity analysis thus facilitating the study of the effects that some parameters variation may have to the resulting hierarchy of the projects.

4 - MCDA Model using FAHP for implementation of SSCM during VUCA conditions
Rhitankar Saha Roy, Karim Ahmed

With the onset of the COVID-19 pandemic and BREXIT, there is a prominent need for further understanding of implications of VUCA conditions and the seismic impact this could have on supply chains. During VUCA times, it has been shown that supply chains struggle on a regular basis to maintain and implement sustainability in their production lines especially for swift decision making for business growth, which are hinged on a set of selected KPIs. This is further exacerbated due to multiplicity of theoretical models that identify KPIs applicable to a particular industry. However, these models do not give these industries the independence to set their own criteria or guide their decision making. Decision making processes for procurement or business area growth can be quite time consuming and is complicated due to the multiple criteria inherent within, which are further complicated during VUCA conditions. As an approach to resolve this, this paper discusses an interactive mathematical tool using modified FAHP based calculation to aid in organizational decision making. This is through suggesting the most sustainable option a supply chain organization can implement based on the multiple criteria and options available to that organization during VUCA times (e.g. COVID-19). This model gives the user/organization the independence to set their own criteria and is not based on a pre-defined list of theoretical KPIs to choose from. Three different case studies have been applied to the

■ MA-30

Monday, 8:30-10:00 - Virtual Room 30

Application of information/knowledge systems for OR decisions

Stream: Information Systems and Software for OR
Invited session
Chair: *Reinaldo Gomes*

1 - Flexible procurement planning for dealing with variability in the availability of raw materials
Reinaldo Gomes, Alexandra Marques, Fábio Moreira, Pedro Amorim

This research was motivated by the forest biomass supply chain, in which it is extremely difficult to predict when and how much forest residues will be available at a certain location, being always dependent on the variability of forest harvesting rates. The efficiency of processing and transportation operations also constrains the amount of material that is delivered at bioenergy plants. This paper studies different flexibility strategies in procurement planning to deal with uncertainty related to spatial and temporal availability of raw materials. The first relates to the possibility to dynamically reconfigure the network design by opening and closing temporary intermediate storage nodes along the time horizon, adjusting to where and how much raw materials are available. The second relates to the possibility to postpone operations from the supply nodes to these intermediate nodes, becoming an instrument for gain economies of scale. The problem is modelled as a mobile Facility Location Problem including Dynamic Operations Assignment (mFLP-dOA) and a fix-and-optimize matheuristic is proposed to obtain good quality solutions for large instances within a reasonable computational time. This study suggests the best flexibility strategy to be adopted, through the assessment of the trade-off between the investment costs in an intermediate node and the efficiency gains resulting from that investment in different disruption scenarios, contributing to better risk management.

2 - Digital Twin on New Product Development in Life Sciences Industry
Rishabh Agrawal, Prateek Jain

Drug development is one of the most complicated Product development process and spans between 15 to 20 years. The development process is usually characterized in 4 phases, each with a hurdle of regulatory approval, post which the drug is released for commercial usage. As per American Council on Science & Health, the overall probability of success for all drugs and vaccines is 13.8%. Hence, there is a high probability of investment not resulting into any benefit which could impact the development of other potential life-saving drugs in pipeline of the organization as well. In such a high-risk, capital intensive & long lead time business, an intelligent planning is needed to reduce the risk for the drug makers and maximize their overall portfolio Robustness and Agility so that more lives around the world could be saved. A Digital Twin is developed using Mixed Integer Linear Programming to guide the investment of constrained resources to maximize the multi-objective attributes such as Speed to First In Human, Speed to New Drug Application, Net Present Value, Robustness, and Agility of the portfolio under uncertainty. The model provides insight into the allocation plan of internal and external resources across projects, prioritization of projects and differential investment strategies. These form an excellent decision support for pharmaceutical companies to improve their drug developing ability and save more lives.

3 - Minimizing transfer distances in port terminals: An integrated Berth Allocation, Quay Crane and Yard Scheduling approach
Emmanouil Thanos, Wim Vancroonenburg, Greet Vanden Berghe

Effective management of container yard usage constitutes a critical component of port terminal operations. This study proposes a model and a heuristic to provide decision support for the combined Berth Allocation, Quay Crane and Yard Scheduling Problem, with the aim being to minimize container transfer distances in the storage yard. The examined problem involves four primary decisions: (i) the assignment of vessels to berthing positions, (ii) the allocation of quay cranes and corresponding serving times to vessels, (iii) the assignment of quay cranes and (un)loading time slots to specific container groups of each vessel and (iv) the allocation of storage blocks to container groups for their entire stay at the yard. Numerous mooring and crane operating restrictions are integrated into the developed model in addition to storage block and container type compatibility constraints. A Remove & Reinsert and a simulation-based heuristic are proposed for the Berth Allocation and the Yard Scheduling component, respectively. Both a functional and a deep integration metaheuristic framework are developed and evaluated over a set of benchmark instances derived from a real-world case. The connection between berth allocations and final container transfer distances is additionally analysed. Finally, derived solutions are also assessed based on their suitability with other practical advantages involved in the terminal operations, such as decrease of congestion and crane usage balancing.

■ MA-31

Monday, 8:30-10:00 - Virtual Room 31

Interactive and Preference based Methods in (Evolutionary) Multiobjective Optimization

Stream: Multiobjective Optimization
Invited session
Chair: *Mariano Luque*
Chair: *Ana Belen Ruiz*
Chair: *Sandra González Gallardo*

1 - Decomposition-based co-evolutionary algorithm for interactive multiple objective optimization
Michał Tomczyk, Milosz Kadzinski

We propose a novel co-evolutionary algorithm for interactive multiple objective optimization, named CIEMO/D. It aims at finding a region in the Pareto front that is highly relevant to the Decision Maker (DM). For this reason, CIEMO/D asks the DM, at regular intervals, to compare pairs of solutions from the current population and uses such preference information to bias the evolutionary search. Unlike the existing interactive evolutionary algorithms dealing with just a single population, CIEMO/D co-evolves a pool of subpopulations in a steady-state decomposition-based evolutionary framework. The evolution of each subpopulation is driven by the use of a different preference model. In this way, the algorithm explores various regions in the objective space, thus increasing the chances of finding DM's most preferred solution. To improve the pace of the evolutionary search, CIEMO/D allows for the migration of solutions between different subpopulations. It also dynamically alters the subpopulations' size based on compatibility between the incorporated preference models and the decision examples supplied by the DM. The extensive experimental evaluation reveals that CIEMO/D can successfully adjust to different DM's decision policies. We also compare CIEMO/D with selected state-of-the-art interactive evolutionary hybrids that make use of the DM's pairwise comparisons, demonstrating its high competitiveness.

2 - Comparison of Interactive Evolutionary Multiobjective Optimization Methods Using an Artificial Decision Maker
Ana Belen Ruiz, Bekir Afsar, Kaisa Miettinen

In interactive evolutionary multiobjective optimization methods, preferences of a decision maker (DM), a domain expert, are iteratively incorporated to generate solutions that reflect the DM's interests. To compare these methods, we need means to capture features inherent in the nature of the solution processes. Namely, the DM's preferences evolve while (s)he learns about the problem's trade-offs and the feasibility of her/his own preferences. In this work, we implement an artificial decision maker (ADM) to evaluate reference point-based interactive evolutionary methods. A reference point consists of desirable values for the objectives. To simulate several iterations with an interactive method, the ADM generates reference points differently depending on two phases that can be distinguished in the solution process. In the learning phase, reference points simulate exploration to examine various Pareto optimal solutions to find a potential region of interest. Then, reference points of the decision phase mimic a progressive convergence towards the most preferred solution in this region. Each reference point is used to assess the methods'performances per iteration. The ADM's performance is demonstrated by comparing several interactive evolutionary methods on benchmark problems with up to 9 objectives. Future work includes consideration of other types of preference information and incorporation of a procedure to automatically switch from the learning to the decision phase.

3 - Visualization tools and practical guidelines for multi-scenario multiobjective robust optimization problems
Babooshka Shavazipour, Manuel López-Ibáñez, Kaisa Miettinen

Recently, multi-scenario multiobjective optimization and the concept of multi-scenario (robust) efficiency have been receiving more attention. In multi-scenario multiobjective optimization problems, the performance of a decision should be evaluated according to all objectives in all plausible scenarios. Thus, scenarios introduce an additional dimension to the solution process and complicate the task of the decision-maker (DM). Visualizations can help a DM understand and compare trade-offs between different objective functions and trade-offs under different scenarios. In traditional multiobjective optimization, visualizations are typically used to represent Pareto optimal solutions in the objective space, helping DMs observe, learn, and evaluate trade-offs between objectives and eventually choose the most preferred solution. In the presence of multiple scenarios, those traditional visualizations fail to capture the trade-offs between scenarios. In this work, we identify some fundamental questions that a DM may wish to answer with the help of visualizations. We help the DMs to answer these questions and make a robust decision by proposing two visualization tools: a novel extension of empirical attainment functions for scenarios and an adapted version of heatmaps. Then, after validating the usefulness of the proposed visualizations with a real DM, we discuss different classes of problems and provide guidelines regarding the best use of the proposed visualizations.

■ MA-32

Monday, 8:30-10:00 - Virtual Room 32

Decision Support in Investment Management & Banking 1

Stream: Multiple Criteria Decision Analysis
Invited session
Chair: *Panos Xidonas*

1 - On ESG multiobjective portfolio optimization
Panos Xidonas, Eric Essner, Paul Chaumard, Romain Rieul

The fundamental principle of the conventional mean-variance framework is that investment decisions are generally made using two criteria, corresponding to the first two moments of portfolio return distributions, namely the expected return and variance. One persistent criticism over this theoretical regime, is that it fails to incorporate the overall spectrum of investors' criteria. Ahead of the new asset management era that calls for sustainably responsible investments, the above limitations need to be resolved. In this paper, we propose a multiobjective minimax-based portfolio optimization model, through which we simultaneously attempt to maximize the three typical ESG investment objectives. Also, apart from the non-systematic risk, the underlying formulation takes into account the, so-called, controversy dimension, associated with each company participating in the optimal ESG-sustainable portfolio. More specifically, the controversy dimension expresses the level at which companies are involved in incidents and events, that may negatively impact stakeholders, the environment or the company's operations. The validity of the attempt is verified through an illustrative empirical testing on the CAC 40, for a 5-years period, using data from Morningstar. We report a series of very encouraging results, since the optimal ESG portfolio produced by the model, appear to possess superior returns in comparison to the market benchmark.

2 - Political risk in internationally diversified portfolios
Stavros A. Zenios, Giovanni Pagliardi

Internationally diversified portfolios carry sizeable political risk premia and we show how to hedge political risk. Using mean to Conditional Value-at-Risk (MTC) optimization to account for the skewed return distributions and drawing inferences using block bootstrapping, we establish that diversification benefits persist when hedging both currency and political risk. The hedged international portfolio of US investors outperforms the index in both MTC and Sharpe ratio metrics, with increases, respectively, from 0.05 to 0.09 and from 0.42 to 0.67. Hedging works even better for long-horizon investors. We also show how to reduce political risk in emerging market portfolios. Short positions in developed markets diversify port- folio political risk while further improving MTC and Sharpe, but both short and long positions have political risk exposures. Results are comparable for Eurozone and Japanese investors, robust to model-implied returns, alternative political risk factors, the great financial crisis, and short positions.

3 - What drives consumer lending in France? A machine learning approach
Constantin Zopounidis, Michalis Doumpos, Panos Xidonas

We develop a machine learning methodology for the identification of the critical factors that drive the credit attitude of households in France. We use a unique dataset based on the Household Finance & Consumption Survey (HFCS) led by European Central Bank (ECB). The HFCS collects information on the assets, liabilities, income and consumption of households. Moreover, relating to individual household members, the survey also covers info, such as various demographics, employment, future pension entitlements and income. The anonymized dataset we exploit is based on the third and most recent wave (2017) of the survey and includes over 13,600 French households. As far as the results, we report that the suggested approach provides valuable insights into the economic behavior and financial situation of households in France, factors that are highly relevant in terms of monetary policy and financial stability.

4 - Comparative Evaluation of Alternative Portfolio Optimization Models: The Case of Funds

Antonios Pavlou, Michalis Doumpos

Nowadays, optimal portfolio selection is a serious issue for both investors and financial consultants. Several models have been proposed, extending the classical mean-variance portfolio theory with the introduction of new performance attributes, but most of them adopt a rather restrictive approach focusing only on a single portfolio without considering the whole set of efficient portfolios. This paper focuses on the performance of the efficient set as a whole. In particular, we examine the out-of-sample robustness of efficient portfolios, by considering both return and risk measures and investigating the outcomes of several portfolio scenarios, from popular optimization models. Tests are conducted using data of 255 funds for 13 years. The results are analyzed through different performance indicators representing the deviations between historical (estimated) efficient frontiers results. The outcomes of the analysis provide insights into the robustness of the models over time, their similarities and differences, and their relative performance under different performance metrics and criteria. This paper also tries to evaluate the previous sample through certain indicators in terms of efficiency in order to highlight the top in their category funds. This will happen through the calculation of different measures for each of the funds to be classified based on their results through two multi-criteria evaluation methods with different weights of importance.

■ MA-33

Monday, 8:30-10:00 - Virtual Room 33

MCDA Methods 3

Stream: Multiple Criteria Decision Analysis
Invited session
Chair: *José Rui Figueira*

1 - Preference disaggregation method for value-based multi-decision sorting problems with a real-world application in nanotechnology

Krzysztof Martyn, Milosz Kadzinski, Marco Cinelli, Roman Slowinski, Salvatore Corrente, Salvatore Greco

We consider a problem of multi-decision sorting subject to multiple criteria. In the newly formulated decision problem, besides performances on multiple criteria, alternatives get evaluations on multiple interrelated decision attributes involving preference-ordered classes. We propose a dedicated method for dealing with such a problem, incorporating a threshold-based value-driven sorting procedure. The Decision Maker (DM) is expected to holistically evaluate a subset of reference alternatives by indicating the quality or risk level on a pre-defined scale of each decision attribute. Based on these evaluations, we construct a set of interrelated preference models, one for each decision attribute, compatible with intra- and inter-decision constraints imposed by such indirect preference information. We also formulate a new way of dealing with potentially non-monotonic criteria by discovering local monotonicity changes in different performance scale regions. The marginal value functions for criteria with unknown monotonicity are represented as a sum of two value functions assuming opposing preference directions, one non-decreasing and the other non-increasing. This permits to obtain an aggregated marginal value function with an arbitrary non-monotonic shape.

2 - Enriched preference modeling and robustness analysis for the ELECTRE Tri-B method

Magdalena Martyn, Milosz Kadzinski

We consider multiple criteria sorting problems with preference-ordered classes delimited by a set of boundary profiles. While significantly extending the ELECTRE Tri-B method, we present an integrated framework for modeling indirect preference information and conducting robustness analysis. We allow the Decision Maker (DM) to provide the following three types of holistic judgments: assignment examples, assignment-based pairwise comparisons, and desired class cardinalities. A diversity of recommendation that can be obtained given the plurality of outranking-based sorting models compatible with the DM's preferences is quantified by means of six types of results. These include possible assignments, class acceptability indices, necessary assignment-based preference relation, assignment-based outranking indices, extreme class cardinalities, and class cardinality indices.We discuss the impact of preference information on the derived outcomes, the interrelations between the exact results computed with mathematical programming and stochastic indices estimated with the Monte Carlo simulations, and new measures for quantifying the robustness of results. The practical usefulness of the approach is illustrated on data from the Financial Times concerning MBA programs.

3 - Performance evaluation of emergency department physicians using robust value-based additive efficiency model

Anna Labijak-Kowalska, Milosz Kadzinski, Luis C. Dias, Wojtek Michalowski

We applied a novel variant of the value-based additive Data Envelopment Analysis model to evaluate Emergency Department physicians' performance using data from the Children's Hospital of Eastern Ontario in Ottawa. In principle, physicians consume three resources: time, laboratory tests, radiology orders, and generate a single output being the quality of the provided care. Our proposed approach's novelty comes from verifying the stability of efficiency outcomes observed for all feasible input and output weights. We also introduce the original procedures for selecting a common vector of weights and an approach for investigating the robustness of results in a multi-scenario setting. Our primary focus in the study is on the physicians' performance when dealing with a group of patients' complaints related to abdominal pain and constipation. However, we also consider two other complaint groups related to fever and lower or upper extremity injury, head injury, and laceration/puncture.

4 - A multiple criteria approach for assessing the quality of the Portuguese public hospitals

Ana Sara Costa, António Rocha, José Rui Figueira, Diogo Ferreira, Rui Marques

The Portuguese National Health Service (SNS) was created to provide universal and equal care, and tendentiously free care. Over the last years, political and economic events have had an impact on the SNS, occurring structural reforms and implementing new healthcare policies. However, they have mainly focused on improving efficiency and reducing costs and, consequently, it associated to divestment can increase barriers to the service's quality. This study aims to assess quality of the Portuguese public hospitals. It is accomplished by using a multiple criteria decision aiding approach due to the multidimensional nature of quality in health. Thus, we consider several criteria and each criterion is characterized by a set of subcriteria structured in a complex criteria tree. Hence, we propose an innovative approach using the ELECTRE TRI-C method for building a multidimensional scale for each criterion. Then, we apply ELECTRE TRI-NC to construct a decision model in cooperation with an expert in the healthcare sector. Considering the hospitals' performances on the criteria and the parameters, the hospitals are assigned to predefined categories (ordered in terms of quality level). We also perform a robustness analysis. This work's findings may have potential application to healthcare policy and hospital funding in the SNS.|Acknowledgements: This work was supported by national funds through FCT in the framework of the project hSNS (PTDC/EGEOGE/ 30546/2017).

■ MA-34

Monday, 8:30-10:00 - Virtual Room 34

Machine Learning and Combinatorial Optimization I

Stream: Combinatorial Optimization
Invited session
Chair: *Gianni A. Di Caro*
Chair: *Matteo Salani*

1 - Detecting infeasibility of resource constrained shortest path problems by data driven models
Marco Casazza, Alberto Ceselli, Cristina Ondei, Marco Trubian

Resource constrained shortest path problems (RCSPP) have wide applicability, representing a flexible model for network applications.

Furthermore, they frequently arise as subproblems in decomposition-based methods, as occurs in column generation for vehicle routing. In all these settings, being able to perform early detection of infeasibility helps to strongly reduce computing times. For instance, in dynamic programming algorithms for RCSPP, extension operations for particular labels can be stopped, if they are found to have no feasible (and profitable) completion. Many fathoming heuristics have been proposed in the literature.

We experiment on using a data-driven approach in this context, modeling the problem of detecting infeasibility as a supervised learning one. We design features which are not dependent on instance size, having different computing cost. We compare the tradeoff between computational effort and performance which can be achieved, when a binary classifier is employed.

Our results indicate such a direction to be promising.

2 - Some insights about the use of machine learning for solving VRP
Flavien Lucas, Romain Billot, Marc Sevaux, Kenneth Sörensen

Hybrid optimisation methods using machine learning tools are a hot topic in combinatorial optimization. The AI promise is to learn from past solutions or in real time what are the markers of good solutions and then to guide the resolution of the problem. However, for many hard problems such as VRP, a wide range of powerful solvers have already proven their efficiency whereas the most recent successes in machine learning (e.g deep learning) need a huge amount of training data before reaching a satisfactory performance level. In this paper, we study the efficiency of a features-guided multiple-neighborhood search (FG-MNS) for realistic instances of HFVRP. The solver is based on two steps. In the learning step, a powerful solver (RADOS) is used to generate a set of solutions, which are characterized by a set of features described in previous work (Lucas et al., 2019, Lucas et. al, 2020). Then, a decision tree is built on this training set to determine where are the promising areas in the features spaces. In a second step, called exploitation step, the solver uses some rules extracted from the decision tree to guide the solution toward a promising area. We present a wide range of experimentations with different variants of the FG-MNS solver (offline, online). While the results are promising for a better understanding of what makes a good solution, the real benefits of machine learning in an industrial implementation are questionable and discussed in this work.

3 - Learning to Schedule Heuristics in Branch-and-Bound
Antonia Chmiela, Elias B. Khalil, Ambros Gleixner, Andrea Lodi, Sebastian Pokutta

Primal heuristics play a crucial role in exact solvers for Mixed Integer Programming (MIP). While solvers are guaranteed to find optimal solutions given sufficient time, real-world applications typically require finding good solutions early on in the search to enable fast decision-making. While much of MIP research focuses on designing effective heuristics, the question of how to manage multiple MIP heuristics in a solver has not received equal attention. Generally, solvers follow hard-coded rules derived from empirical testing on broad sets of instances. Since the performance of heuristics is instance-dependent, using these general rules for a particular problem might not yield the best performance. In this talk, we propose the first data-driven framework for scheduling heuristics in an exact MIP solver. By learning from data describing the performance of primal heuristics, we obtain a problem-specific schedule of heuristics that collectively finds many solutions at minimal cost. We provide a formal description of the problem and propose an efficient algorithm for computing such a schedule. Compared to the default settings of a state-of-the-art academic MIP solver, we are able to reduce the average primal integral by up to 49% on a class of challenging instances.

4 - A new variant of Kernel Search applied to the Multidimensional Multiple-choice Knapsack Problem
Renata Mansini, Leonardo Lamanna, Roberto Zanotti

The Multidimensional Multiple-choice Knapsack Problem (MMKP) is a challenging combinatorial optimization problem. Recently, several heuristic approaches and a few exact algorithms have been proposed for its solution. Thanks to them, it has been possible to obtain new best-known values for benchmark instances, even if many of such instances are still not solved to optimality. In this paper, we provide a new variant of the matheuristic framework Kernel Search and apply it to the MMKP. The proposed variant keeps the method's main idea of solving a sequence of restricted mixed-integer subproblems but innovates by partitioning the method into two different phases with complementary goals and by changing the way the kernel set is selected and updated. The first phase strives for feasibility and terminates by providing important information to dynamically adapt subproblems dimension and solution time in the second phase that is focused on obtaining high-quality solutions. This makes the global approach more scalable and efficient. Computational results on different sets of benchmark instances demonstrate that the method is extremely effective, outperforming all state-of-the-art heuristics for the MMKP. The method compares extremely well also with respect to exact approaches running for five hours. The proposed algorithm has improved the best-known value of 185 out of 276 open benchmark instances and its average deviation from optimality is always negligible.

■ MA-35

Monday, 8:30-10:00 - Virtual Room 35

Topics in Combinatorial Optimization I

Stream: Combinatorial Optimization
Invited session
Chair: *Martin Branda*

1 - The Reward-Penalty-Selection Problem
Till Heller, Karl-Heinz Küfer, Sven Krumke

The Set Cover Problem (SCP) and the Hitting Set Problem (HSP) are well-studied optimization problems. In this talk we introduce the Reward-Penalty-Selection Problem (RPSP) which can be understood as a combination of the SCP and the HSP where the objectives of both problems are contrary to each other. In the RPSP one is given a finite ground set of elements N, reward sets A_i with corresponding nonnegative rewards a_i and penalty sets B_j with corresponding nonnegative penalties b_j. Let S be a selection of elements from the ground set. We say that a subset C of N is covered by S if C is a subset of S, and that C is hit by S if the intersection of C and S is non empty. The task in the RPSP to find a subset of elements S such that the sum of rewards of reward sets covered by S minus the sum of penalties of penalty sets hit by S is maximized/minimized. The RPSP has applications in the context of combinatorial exchanges. We show that the maximization variant of the RPSP is polynomial solvable while the minimization variant is NP-complete in general. We also exhibit polynomially solvable special cases such as laminar sets or the situation where the natural bipartite element-set incidence graph has bounded tree width.

2 - The balanced maximally diverse grouping problem with attribute values
Arne Schulz

The balanced maximally diverse grouping problem with attribute values (BMDGPAV) is a variant of the well-known maximally diverse grouping problem (MDGP) which assigns items to groups such that the sum of absolute differences of all item pairs assigned to the same group is maximized. In the BMDGPAV absolute differences are absolute differences of the attribute values of the corresponding items. This is a realistic setting for example in the assignment of students to courses according to their academic achievements. Moreover, BMDGPAV searches for a best-balanced solution amongst all solutions with maximal sum of intra-group differences (i.e. optimal solutions of the corresponding MDGP instance). We present theoretical insights as well as solution approaches and a computational study for the BMDGPAV.

3 - New Formulations for the TSP
Trilochan Sastry, Ashish Singh Bhandari

New formulations for the TSP Trilochan Sastry and Ashish Singh Bhandari Indian Institute of Management, Bangalore We consider polynomial formulations of the symmetric TSP with an enhanced set of variables. The number of variables and constraints are both O(n3) where n is the number of nodes in the tour. This formulation was tested on some of the challenge problems and all except one were solved to optimality. The basic idea is to fix the location of the nodes using three methods. One is using commodity flows where one commodity flows from node 1 to each of the remaining nodes. This is well known in the literature and subsumes the sub-tour constraints. Another is to number the nodes in the tour from 1 to n. A third is to measure the distance between any two nodes. These two sets of variables are new. The model then links these three sets of variables. For instance, if we measure the total number of arcs through which commodity k flows, it turns out that this equals the position of node k on the tour. The model was tested on various well known problem instances and gives optimal solutions in all cases except one. It also opens up some interesting research questions about the well known valid inequalities and this formulation. We also present some alternate formulations using the notion of permutations and combinations.

4 - Fixed interval scheduling problems with endogenous uncertainty
Martin Branda

Fixed Interval Scheduling deals with problems where jobs with fixed processing intervals are assigned to available machines. If the finishing times of the jobs are uncertain, the possible criteria involve expected number of unfinished jobs which is minimized. This leads to a stochastic two stage integer programming problem which can be reformulated as a robust coloring problem with suitable choice of the penalties. In this paper, we focus on the problem where the delay distribution can be influenced by our decisions, e.g. by inclusion of the maintenance operations. This leads to the problem with endogenous uncertainty. We will propose a possible formulation and reformulation using an extended robust coloring problem. We will also propose a numerical study on simulated instances.

■ MA-36

Monday, 8:30-10:00 - Virtual Room 36

Investment Choices

Stream: Corporate strategies
Invited session
Chair: *Javier Giner*

1 - Interval transition probabilities for alternating Semi Markov Chains under Negative Binomial and Gamma distribution
Javier Giner, Valeriy Zakamulin

Despite the ever-growing interest in Semi Markov Chains (SMC) and their applications in a wide range of areas, there is still a great shortage of theoretical results on the properties of these models. Our paper fills this gap by introducing a novel technique to analyze SMC through pure Markov Chains by forcing the states to stay more periods with the result of modifying the original Geometric distribution state holding time into a Negative Binomial distribution. This allows to introduce increasing hazard rates what is a desirable property. The general method is introduced, applicable to every n-state SMC where holding times follow negative binomial distribution. Then, the 2-state SMC is deeply analyzed for the following main combinations, NB(2)+Geo and NB(2)+NB(2). Closed-form solutions for the interval transition probabilities are derived. The continuous time case where exponential and gamma distributions are employed is also considered. Overall, the results reported in this paper help to understand more deeply the properties of SMC as well as the differences and similarities between them.

2 - Study of the market through co-movement in volatility
Maria de las Nieves López-García

In this paper, we focus on the growing interest in the study of the co-movement of volatility, as its movement affects financial assets in various ways, exerting a great influence on risk management, portfolio selection, pricing of derivatives and for setting regulatory policy. To study co-movement, we borrow from the analysis of many-body physical systems (colloidal systems) and adapt it to financial markets. Our approach from physics considers a portfolio as if it were a system of many bodies, using the index to represent a characteristic point that characterizes the whole system, such as the center of mass. Following the classical mechanics of multi-body systems, internal forces only affect the relative motion of a body with respect to the center of mass, so a proper estimate of co-motion due to interactions, within a physical approach, can only be made by subtracting the center of mass (or index). However, we are also interested here in the co-movement of the full market, without subtracting the center of mass. We find that stocks with similar volatility tend to have a greater co-movement than stocks with dissimilar volatility, with a general decrease of co-movement with increasing volatility. On the other hand, when the average volatilityis subtracted from the stock volatility, the co-movement decreases notably and becomes almost zero. This allows us to identify the index motion as the main source for the co-movement.

3 - Prioritizing of ambulances mobility based on a bi-criterion and multistage approach in overload situations
Stamatios Vasalakis, Athanasios Spyridakos

This research work aims to the development of a deterministic methodological approach for transportation problems of the ambulances in natural disasters, where there are strong needs for immediate response and the number of cases is high. The proposed methodological approach is based on the principles of Dynamical Programming (DP) which discretize the optimization problems in stages and the techniques of Linear Programming (LP) for the identification of the optimal transportation plan at every stage. In addition, the dynamic of the problem is enhanced by the usage of live data from the Google. This kind of problem is considered multiplicative while there are two principal objectives a) the emergency to transport the injured according to their triage scale and b) the immediate movement of the patients to the hospitals. Also the problem can be characterized multiplicative because of a) the existence of many start points and destination points of the ambulances with different distances and availabilities, b) the destination points of one stage becomes the start points of the next stage increasing the multiplicity of the problem and c) the need to achieve a global optimization of the time response in relation to the emergency and priorities of the patients' condition. The above proposed methodological approach is illustrated through a case study involving the timely transfer of injured people as a result of a natural disaster to the nearest Hospitals at local level.

4 - Investment, strategic debt service, and liquidation
Takashi Shibata, Michi Nishihara, Yuan Tian

We develop a contingent claim model to examine the interaction between a firm's financing and investment decisions, on the condition that the firm has the options of strategic debt service and liquidation during the financial distress. We show the effects of strategic debt service under liquidation option.

■ MA-37

Monday, 8:30-10:00 - Virtual Room 37

OR for DNA sequences

Stream: OR in Computational Biology, Bioinformatics and Medicine
Invited session
Chair: *Artur Laskowski*

1 - Alignment-free sequence comparison: A systematic approach from a machine learning perspective
Katrin Sophie Bohnsack, Thomas Villmann

The encounter of large amounts of biological sequence data arisen during the last decades and the algorithmic and hardware improvements has offered the possibility to apply machine learning techniques in bioinformatics. While in the machine learning community there is awareness to rigorously distinguish data transformation from data comparison and adopt reasonable combinations thereof, this strategy is often lacking in the field of comparative sequence analysis. With realization of the disadvantages of alignments for sequence comparison, some of the typical applications are shifting to the branch of so-called alignment-free (AF) approaches. In the light of this development, we present a conceptual framework for AF sequence comparison, which strengthens the delineation of: 1) the sequence data transformation comprising adequate mathematical sequence coding and feature generation, from 2) the subsequent (dis-)similarity evaluation of the transformed data by means of problem-specific but mathematically consistent proximity measures. We consider coding to be an information-loss free data transformation in order to get an appropriate representation, whereas feature generation is inevitably information-lossy with the intention to extract just these information relevant for the task. This distinction sheds light on the plethora of methods available and assists identifying suitable methods in machine learning and data analysis to compare the sequences under these premises.

2 - GrassSV - a hybrid tool for detecting Structural Variants
Aleksandra Swiercz, Dominik Witczak, Krzysztof Sychla, Wojciech Frohmberg, Julia Wysocka, Jacek Blazewicz

Every two genomes of the same species are different. Differences can be short, called SNP, or longer, called Structural Variants (SV). We propose a tool GrassSV for detecting structural variants of different types: deletions, duplications, insertions, inversions, and translocations. GrassSV first maps short reads onto a reference genome, and then detects regions with abnormal coverage (too low or too high). In these regions we perform assembly de novo with assembler GRASShopPER for proper reconstruction of potential differences. Reconstructed contigs are then mapped again to the reference genome allowing for partial mapping. Basing on the mapping patterns, specific for every type of genetic variant, we can detect various SV. Computational experiments performed on the genome of yeast shows that GrassSV is the most versatile among all tested tools, which are usually specialized in one type of SV.

3 - Assembly-free comparison of genomic data
Artur Laskowski, Pawel Wojciechowski, Sylwester Swat, Jan Badura, Aleksandra Swiercz, Jacek Blazewicz

Calculating the similarity of genomic data is a crucial task. One could use similarity measures to decide whether given data comes from the same species or not. If the measurement is accurate enough, one could calculate the number of structural variants among a group of individuals from the same species. Calculations like that could lead to a better understanding of the evolution process and understatement of how individuals from across the world mix with each other. Nowadays, such analyses could only be performed with assembled data since ANI and Mash measurements, state-of-the-art methods, are calculating the similarity of genomes. The assembling process is highly time-consuming, and for calculation of the human genome could take more than 12 hours. In this work, we would like to introduce the assembly-free process of comparing genomic data in the form of long-read sequences produced by NGS sequencers like Illumina. In contrast to state-of-the-art methods, our method is quick and could produce results within minutes.

4 - Efficient Numerical Methods for the Solution and Parameter Estimation in Multiscale Models of Hepatitis C Viral Dynamics
Danny Barash, Alexander Churkin, Vladimir Reinharz, Stephanie Lewkiewicz, Harel Dahari

Age-structured multiscale models that consider RNA viral replication have been developed to study viral dynamics. However, they are notoriously difficult to solve and when utilizing this type of models parameter estimation presents a challenge. Here, we investigate the numerical solutions of a multiscale model of hepatitis C virus (HCV) dynamics during antiviral treatment and compare them with analytical approximations. First, we show that considerable gain in efficiency can be achieved by using adaptive stepsize methods over fixed stepsize methods for simulating realistic scenarios when solving multiscale models numerically. We compare between several numerical schemes that are suitable and show the benefit of using the Rosenbrock method, an implicit adaptive stepsize method that is both efficient and stable. Second, we address parameter estimation by constrained optimization and show that derivative-free methods such as Powell's constrained optimization by linear approximation (COBYLA) provides an efficient procedure for this task.

■ MA-38

Monday, 8:30-10:00 - Virtual Room 38

Scheduling in Healthcare

Stream: ORAHS: OR in Health and Healthcare
Invited session
Chair: *Elena Tanfani*
Chair: *Paolo Landa*

1 - Quantifying the required resources for a central sterile supply department
Theresia van Essen, Guusje Scheijen, Thomas Schneider

Optimizing supply chain management in hospitals can lead to a significant reduction in costs. One of the supply chain processes that can be optimized is the sterilization of reusable instruments used during surgical procedures. This process takes place at the Central Sterile Supply Department (CSSD) and consists of two main steps, 'washing and disinfection' and 'sterilization'. In this research, the aim is to determine the required resources of the CSSD, while minimizing the total costs and guaranteeing the availability of instruments for scheduled surgeries. The problem is described as a multi-stage hybrid flow shop with additional constraints to represent the specific characteristics of the CSSD and is proven to be NP-hard. Therefore, a decomposition method is proposed, resulting in three optimization models. The strategic model takes into account the scheduling of instruments per day, while the tactical model schedules per day parts, and the operational models determine a specific point in time. The proposed heuristic approach forms a chain of the models. The best results for the case of Leiden University Medical Center were obtained by setting a minimum amount of opening time for the strategic model and using the resulting machines as input for the tactical model.

2 - Multi-objective optimization for constructing cyclic appointment schedules for elective and urgent patients
Tine Meersman

The paper studies the construction of a cyclic appointment schedule in an outpatient department. In particular, we determine the capacity distribution between elective and urgent patients and the timing of the time slots reserved for these patients such that the operational waiting times for elective and urgent patients are minimized. The proposed solution methodology forms a Pareto set of cyclic appointment schedules based on these waiting times with different capacity allocations to urgent patients. An approximation of the Pareto set of non-dominated schedules is obtained using a multi-objective archived simulated annealing heuristic. In order to validate the cyclic appointment schedules in an accurate manner, we incorporate operational decision-making related to the scheduling of individual patients. For that purpose, we simulate the operational variability i.e., the patient arrival, the no-show behaviour, the patient punctuality and the scan duration, based on real-life input data. The patients are assigned one-by-one using an online scheduling rule. Computational experiments have been conducted for a real-life case study. We compare different appointment scheduling rules and discuss the impact of the capacity distribution between elective and urgent patients and the timing of the urgent slots in the cyclic appointment schedule.

3 - Capacity allocation and appointment scheduling under service disruption and supply uncertainty
Ka Yuk Carrie Lin

Out-patient services are disrupted by external and internal factors from time to time, like the pandemic and priorities in manpower allocation. Rescheduling appointments, cancellations and backlogs are inevitable. In the public specialist out-patient clinics in Hong Kong, additional challenges involve maintaining the service targets in the urgent and semi-urgent categories of new cases based on their waiting time percentiles. New cases generally take longer consultation time than follow-up cases, but the latter constituted a large proportion of total patient attendance in each specialty. In a recent 6-year period in the three largest specialist services, the increase in demand from new cases exceeds the actual attendance mainly based on capacity (quota) allocated. This study proposes an operational strategy of simultaneous capacity allocation and appointment scheduling for new and follow-up cases in specialist outpatient clinics over a multi-day planning horizon. Experiments are designed using sample data collected in the Ophthalmology clinic of a major public hospital, data from annual government meetings and the hospital website. With the aim of being robust enough to react to changes, heuristic scheduling rules for adjusting the capacity, appointment quota between new and follow-up cases, will be developed. A mixed integer linear programming model is formulated to provide benchmarks for performance evaluation when information is known retrospectively.

4 - An appointment scheduling problem for pre-admission testing with COVID-19 related constraint
Mauro Passacantando, Giuliana Carello, Luca Varesi

Pre-admission testing is a set of medical examinations that a patient must undergo a few days before surgery to check if the patient can receive the planned surgery. It is very important to timely plan the pre-admission appointments, as a delay may delay the surgery, leading to underutilization of the operating rooms. We consider a pre-admission testing service where the resources, staff, and rooms for visits, are shared among several specialties. Many problems arise in managing a shared pre-admission testing service: the rooms and time slots must be assigned to the different specialties, the clinician and nurse rostering must be planned, and the appointments must be scheduled. We focus on the problem of scheduling patients' appointments throughout the day. The time slots assigned to the specialties are known as well as the visits and testing each patient must undergo. Due to the pandemic situation, a limited number of patients can be simultaneously present in the hospital. We have to assign an entry time to each patient and schedule each step of the pre-admission testing procedure, to guarantee that all the patients are visited and the COVID-19 restriction is met. We propose a model-based decomposition heuristic that provides good results on a set of real-life-based instances.

■ MA-39

Monday, 8:30-10:00 - Virtual Room 39

Complex routing and location problems II

Stream: Routing, Logistics, Location and Freight Transportation
Invited session
Chair: *Anne Lange*

1 - Optimal route selection for oversize and heavyweight cargo transportation considering bridge carrying capacity
Christian Wankmüller, Andreas Felsberger, Christian Truden

The transportation of oversize and heavyweight cargoes (OHC) represents one of the most challenging processes in freight movement, frequently leading to time-consuming and costly road closures, traffic congestions and temporary manipulations of the infrastructure. This sector is gaining massive momentum due to an increase in global trade volume and a rising demand for specialized items delivery. Among cost and time-related factors, security and safety issues have top priority when undertaking OHC transportation on the road. Planning such transports is complex due to a multitude of criteria that needs to be evaluated before determining the final transport route. Aside from physical road characteristics, road turning radius and transportation corridor widths, the maximum bridge carrying capacity is a safety-relevant parameter that determines the quality of OHC transports. Historical incidents, such as the Genoa bridge collapse in 2018, are negative examples where poor maintenance along with unqualified planning and non-compliance to standards and regulations when transporting OHC over routes that include bridge segments. This study takes up the problem of selecting the optimal route for OHC transportation and proposes an integer linear model with the objective to minimize road distance while considering maximum bridge carrying capacities. We test the model to balance cost, time and safety of OHC transportation using data of the Austrian highway network.

2 - Biobjective Approaches for Locating a Semi-Desirable Facility
Diclehan Tezcaner Öztürk, Fatma Ersoy

We address the location problem of a semi-desirable facility in a continuous area. We consider two objectives: minimization of the total transportation cost between the facility and the demand points, and minimization of the undesirable effects. We assume that the transportation cost is proportional to the Rectilinear distances between the facility and the demand points. For the second objective, we minimize the social cost that is a function of the Euclidean distances between the facility and the demand points. In our solution approach, we find the regions in the continuous area that the efficient solutions may lie. We then approximate the nondominated frontier of each region. Using the approximated frontiers and the preferences of the decision maker, we generate the preferred efficient solutions.

3 - Transportation planning for a retail depot aiming to minimize total tour cost in a multi-tour vehicle routing problem; A model and a heuristic solution approach
Behiye Eda Çabuk, Kadir Ertogral

We tackle a multi-tour vehicle routing problem with time windows where the objective is the minimization of total cost of tours in the context of a transportation problem for a depot of a retail chain. On a daily basis, the depot has to decide which retail store's demand should be carried in which vehicle and in which tour. The transportation service is provided by a third party logistic company. The total cost of a plan to the depot is based on the number of tours made by the vehicles. We have a heterogeneous fleet of vehicles with different capacities and with different per tour costs. A vehicle can make multiple tours. The demand for each store is known as the number of pallets every morning. There is compatibility issue between stores and vehicle types, and some stores have service time window restriction. We both suggest a mixed integer programming model for the problem and a heuristic solution approach since the problem is in NP hard class. The heuristic is a randomized, greedy, constructive type of approach based on making economically acceptable tours prioritizing the use of larger capacity vehicles. We show the effectiveness of the heuristic in a set of problems, both randomly generated and based on a real life case.

4 - The role of dispatching strategy and service frequency in creating transportation network travel time reliability
Anne Lange, Marion Baumann, Kai Furmans

When travel times are reliable, passengers arrive at their destinations at the scheduled time. Travel time reliability in transportation networks is sensitive to transfers at intermediate stations, and the dispatching strategy (wait for connecting passengers or depart as scheduled) affects passenger delays. Moreover, the frequency of connecting services will impact travel time reliability as it implies the waiting time for a missed connection. Low travel time reliability incentivizes travelers to plan for an early arrival to ensure on-time arrival - which is a highly inefficient use of time and thereby a reduction in welfare. Such time buffers will have an operational cost in business settings. Achieving on-time arrival in a complex transportation network requires a solid understanding of the parameters that influence the distribution of travel times.

We develop a mathematical model, which allows us to assess travel time reliability from a passenger's point of view as a function of the types of transfers (network structure), dispatching strategy and service frequency. We design stylized scenarios to identify structural trade-offs related to the above parameters.

Our model can be applied to many planning task of transports with transfers and regular services, such as network-based freight or passenger transportation and multi- / intramodal urban transportation.

■ MA-40

Monday, 8:30-10:00 - Virtual Room 40

Waste collection problems

Stream: Routing, Logistics, Location and Freight Transportation
Invited session
Chair: *Carolien Lavigne*

1 - Solving a Sensor Placement Problem in Waste Management based on a Vehicle Routing Problem with Detours
Carolina Soares de Morais, Tania Ramos, Daniele Vigo, Ana Paula Barbosa-Póvoa

Waste Management faces inefficient collection and transportation of solid waste due to an incapacity of accurately allocate the resources to the waste demand. If sensors are used to communicate the amount of waste inside the containers, more efficient collection routes can be designed, resulting in a reduction of unnecessary mileage traveled. As the cost of implementing this technology is still very high, we select a sample of containers to monitor, considering the investment cost and the value of information provided by sensors. To decide which containers to monitor, we use a clustering algorithm to group containers that have similar filling rates and are located nearby; then, clusters are classified as remote or non-remote, depending on their collection frequency. The most representative container within each remote cluster is monitored, avoiding the cost of traveling long distances unnecessarily. We tackle this problem as a VRP with detours, where the non-remote containers are served by a regular route, which is modified to visit remote clusters when needed, based on sensor information. A real-world problem is solved through our approach, and three scenarios are assessed by a cost-benefit analysis: 1) no sensors - all containers are visited on a regular basis; 2) sensors in all containers - containers are visited only when it is required; 3) a set of containers is monitored - a regular route is performed and, when it is required, a remote cluster is visited (detour).

2 - A hybrid genetic algorithm for solving rich waste collection problems
Carolien Lavigne, Dirk Inghels, Wout Dullaert, Reginald Dewil

This paper presents a Hybrid Genetic Algorithm (HGA) for solving a large variety of waste collection problems with multiple depots, a restriction on the fleet stationed at each depot, multiple (intermediate) processing facilities, capacity restrictions per processing facility and partial pick-ups. The HGA first generates satisfactory solutions which are feasible w.r.t. the shift duration and the vehicle capacity using a novel procedure in which (1) a giant tour is split into vehicle routes, (2) intermediate processing facilities are introduced and (3) waste pick-ups can be split further. Second, the HGA improves these solutions through local search in which adapted versions of well-known move operators are combined with move operators found in the partial pick-up literature. The HGA is compared with an exact approach on a small example and is tested on existing instance sets for the multiple-depot vehicle routing problem (MDVRP) and the MDVRP with intermediate facilities (MDVRPI). The HGA shows competitive results, especially for MDVRPI instances in which vehicles can leave multiple depots. The HGA is used to solve a real-life waste collection problem in the Brussels Capital Region in which alternative scenarios for municipal bio-waste collection and treatment are compared.

3 - Capacitated Multi Depot Green Vehicle Routing for Transporting End-of-Life electrical waste
Andreas Häggström, Karl-Johan Djervbrant

A comprehensive study is presented of the Capacitated Multi Depot Green Vehicle Routing Problem (CMDGVRP) applied to a heterogenous fleet of electronic waste collecting vehicles with two objectives: to reduce the total fuel consumption of the vehicles (environmental constraint) and to limit the continuous drive-time of the drivers (social constraint). Research has been limited from this aspect and in this study the focus is on the practical application of pickup and delivery of electronic waste. The study also presents results for the online dynamic routing variant of this problem, where a traffic congestion appears mid-route. A detailed analysis and parameter optimization has been done for the local search algorithms, Simulated Annealing, and Genetic algorithm (GA), along with more advanced variants like Non-dominated Sorting GA (NSGA II), NSGA III, UNSGA III and Indicator-Based Selection Evolutionary Algorithm (IBEA). Results are presented from realistic simulation studies on a public dataset, with varying route lengths and vehicle fleet sizes, along with a real-world dataset from a waste collection company in Sweden. The results show that the optimal choice of algorithm depends on the dataset size and if there is a maximum budget of evaluations or computation time. Realistic problems are solved in a matter of a few seconds given that they are initiated well. Local search algorithms prove to be very competitive for large problems and limited computation time budget.

4 - A facility location model to improve e-waste recovery from households
Nitin Koshta, Sabyasachi Patra

E-waste is the fastest growing solid waste stream having an average annual growth rate of 4%-5%. The huge amount of e-waste generated globally, every year, demands effective and efficient waste management practices. In the recent past, researchers have made increasing attempts to understand and improve e-waste management. However, the prior literate is majorly concentrated on two themes (a) designing policies, and (b) understanding psychological determinants of peoples' recycling intention. Moreover, very limited efforts have been made to strengthen the reverse logistics network to improve e-waste recovery from households. We propose a multi-objective mixed-integer programming model for setting up collection centres for e-waste recovery from households to address this issue. The proposed model is justified and its applicability is demonstrated by taking the case of Delhi. The study is of importance to the policymakers and decision-makers engaged in setting up an e-waste recovery network.

■ MA-41

Monday, 8:30-10:00 - Virtual Room 41

Extensions of the resource-constrained project scheduling problem

Stream: Scheduling and Project Management
Invited session
Chair: *Mario Vanhoucke*
Chair: *Annelies Martens*

1 - An efficient genetic programming approach to design priority rules for resource-constrained project scheduling problem
Jingyu Luo, Mario Vanhoucke, José Coelho, Weikang Guo

In recent years, machine learning techniques, especially genetic programming (GP), have been a powerful approach for automated design of the priority rule-heuristics for the resource-constrained project scheduling problem (RCPSP). However, it requires intensive computing effort, carefully selected training data, and appropriate assessment criteria. This research proposes a GP hyper-heuristic method with a duplicate removal technique to create new priority rules that outperform the traditional rules. The experiments have verified the efficiency of the proposed algorithm as compared to the conventional GP approach. Furthermore, the impact of the training data selection and fitness evaluation has also been investigated. The results show that a compact training set can provide good output, and existing evaluation methods are all usable for evolving efficient priority rules. The priority rules designed by the proposed approach are tested on extensive existing datasets and newly generated large projects with more than 1,000 activities. To achieve better performance on small-sized projects, we also develop a method to combine rules as efficient ensembles. Computational comparisons between GP-designed rules and traditional priority rules indicate the superiority and generalization capability of the proposed GP algorithm in solving the RCPSP.

2 - Ranking components of the branch-and-bound procedure for the resource-constrained project scheduling problem via machine learning
Weikang Guo, Mario Vanhoucke, José Coelho, Jingyu Luo

The branch-and-bound (B&B) procedure can be used to find the optimal solution for the resource-constrained project scheduling problem (RCPSP). Various components have been assembled into a unified search algorithm to select the best performing bounds, including branching schemes, search strategies, and dominance rules. However, due to high computational time, the B&B method is only suitable for small-size problems. Moreover, preference information regarding the performance of different components is often not available.

In this research, we introduce a structured prediction approach to learn a mapping from project indicators to a ranking over a given set of components of the B&B method for the RCPSP. The objective is to rank different components used in the procedure to obtain the best possible LB/UB within a reasonable time. An extensive computational experiment is set up to verify the performance of the introduced prediction model and the impact of different components of the B&B method on the benchmark dataset. The experiments indicate that the proposed prediction model outperforms any single component. Further, we also analyze the robustness of the model on subsets with different number of activities.

3 - On the resource-constrained project scheduling problem with categorical and hierarchical skills
Jakob Snauwaert, Mario Vanhoucke

This research focuses on the multi-skilled resource-constrained project scheduling problem, further abbreviated as MSRCPSP, with categorical and hierarchical skills. Categorical skills represent the degree of multi-skilledness of the resources. Since the resources need specific categorical skills to work on an activity, categorical skills introduce an assignment restriction to the problem. But due to the fact that a resource can possess multiple skills, categorical skills also generate more assignment flexibility. The hierarchical skills express the degree of mastered skill experience or proficiency of the resources. The impact of hierarchical skills on the project scheduling problem can be manifold. In this research, we set out several different consequences of hierarchical skills, some of which have already been studied in the multi-skilled project scheduling literature, such as task restriction or resource efficiency, and some of which are entirely new to this problem, such as commodity usage and resource attunement. Moreover, we present mathematical formulations for each of these extensions to be able to solve the problems and explain their inherent similarities and differences. The computational experiments are conducted on problem instances derived from real-world data, to assess the performance of these formulations.

4 - A theoretical framework for instance complexity of the resource-constrained project scheduling problem
Rob Van Eynde, Mario Vanhoucke

The resource-constrained project scheduling problem (RCPSP) addresses the problem of constructing a schedule with minimum makespan for a set of activities, subject to precedence and resource constraints. Recent research introduced a dataset with small instances that cannot be solved by the state-of-the-art exact algorithms, revealing a gap in our understanding of instance complexity. We propose a new theoretical framework for the instance complexity for the RCPSP, consecutively incorporating precedence constraints, resource constraints and activity durations. Our approach contributes to the existing knowledge base in two ways. First, it is independent from solution algorithms, which enables generalizable conclusions. Second, the theoretical perspective enables a deeper understanding of the drivers of instance complexity. The discriminative and predictive power of our approach is validated with a series of computational experiments. Furthermore, the results suggest that completely different solution procedures will be required to solve the most difficult instances.

■ MA-43

Monday, 8:30-10:00 - Virtual Room 43

Stochastic models in chronic and home care management

Stream: Stochastic Modeling in Health Care
Invited session
Chair: *Evrim Didem Gunes*

1 - Chronic patients' adherence to therapy: Sensitivity to patients' time preferences by Markov decision process
Hakan Kılıç, Evrim Didem Gunes

Chronic patients' non-adherence to therapy leads to suboptimal health outcomes and a heavy burden to the healthcare system. In their decision to adhere to therapy, it is expected that patients weigh immediate gains against delayed gains, e.g., a patient may consider dieting to result in health gains which are so much delayed that it is not worth to forgo the indulgence of not dieting. We investigate such problems theoretically by modelling it as a Markov decision process (MDP), where the actions are to adhere to therapy or not. Our main focus is to understand how a patient's time preferences, i.e., discounting behaviour, affects her adherence to therapy. To that end, discrete time infinite horizon MDPs with discounted expected total reward maximization are studied to estimate how the magnitude of the discount factor (δ) reflecting exponential discounting influences the optimal policy. We show monotone optimal policy in δ under sufficient conditions. The delay-discounting literature generally considers hyperbolic discounting. Therefore, quasi-hyperbolic discounting (β, δ) which models present-biased naïve decision makers is also investigated. We present a method to solve infinite horizon Markov decision processes with quasi-hyperbolic discounting. Then, we demonstrate monotone optimal policy in δ and in β under sufficient conditions. Furthermore, under quasi-hyperbolic discounting, the effect of δ on optimal policy is compared against the effect of β.

2 - Multi-channel chronic patient care in a performance-based reimbursement framework

A. Mete Ozbek, Hessam Bavafa, Evrim Didem Gunes, E. Lerzan Ormeci

We model and analyze the Comprehensive Primary Care Plus (CPC+) reimbursement system that was recently introduced by the Centers for Medicare & Medicaid Services. Our model includes a primary care practice (PCP) as a profit-oriented service provider with limited capacity. PCP employs multiple channels of care in handling demand of patients with chronic conditions to maximize its revenue in the existence of additional financial incentives. We analyze the operational decisions of the PCP, in particular the panel size and time allocated to different channels, under CPC+ and investigate conditions under which CPC+ could encourage the PCP to improve the quality of care for chronic patients.

3 - A robust framework with dynamic reassignments for the home health care nurse-to-patient assignment with continuity of care

Giuliana Carello, Lucia Galperti, Ettore Lanzarone

A major challenge in managing Home Health Care services is to ensure continuity of care despite uncertain patients' evolutions when assigning nurses to patients. Providers face the trade-off between reassigning patients to balance workloads, and keeping the assignments to guarantee continuity of care. A possible solution could be to solve the problem for a long planning horizon, to provide the assignments of nurses to all patients, and to periodically rediscuss the assignments when the actual demands are known for those patients who accept a weaker continuity of care. We consider a nurse-to-patient assignment problem where patients require three different capacity of care levels. We propose an approach that addresses uncertain and time-correlated requests for visits, and dynamic assignments. The long-term assignments are provided by solving a robust model through the Implementor-Adversary approach, to include time-correlation in the uncertainty set of patients' requests for visits. We provide two formulations for the problem, with either constant or increasing overtime cost. The Adversarial problem aims at building the requests realizations that maximize the costs while selecting the short-term assignments that minimize them. It turns out the be a challenging problem; thus, we provide three heuristic approaches to speed up the process. The framework has been applied to realistic instances, and the results confirm the effectiveness of the approach.

■ MA-44

Monday, 8:30-10:00 - Virtual Room 44

Optimization in Manufacturing and Mainetance

Stream: Engineering Optimization II
Invited session
Chair: *Wolfgang Achtziger*

1 - An Efficient Neighborhood Search for the Tool Indexing Problem with Tool Duplications

Deepti Mohan, Diptesh Ghosh

Automated machining centers are a critical part of modern manufacturing facilities such as automobile and aircraft part manufacturing. Such centers feature automatic tool changers for enabling computerized tool changeovers. Tool changing times form a significant portion of the non-machining (dead) time in job processing. Hence minimization of tool changing time by optimally arranging tools in the pockets of the tool magazine is crucial in achieving profitable operation. This is known as the tool indexing problem and is a quadratic assignment problem. Exact solution methods often fail to obtain optimal solutions for practical size problems in a reasonable time. We look at tool indexing problem with tool duplications where multiple copies of each tool are allowed in the tool magazine. For this problem, evaluating the objective function for a given arrangement itself is a stand-alone problem as it requires constructing a network and solving for the shortest path problem in the network. Hence this is a computationally challenging problem. We propose an efficient approach for updating the objective function value during the neighborhood search and further exploit the problem characteristics to develop an efficient neighborhood search for the problem.

2 - Assessment of the environmental and economic impact of the production process of carbon-nanostructures for lime-based mortars for cultural heritage interventions

Nikolaos Alexopoulos, Anastasios Gialos, Vasileios Zeimpekis, Aggeliki Dimou, Ioannis Frezoulis, Christina Charalampidou, Dimitrios Gournis, Michael Karakassides, George Asimakopoulos, Zoi Metaxa, Ioannis Karatasios

The unchecked outflow of Green House Gas has led the industries to consider the environmental impact as one of the most important factors during the development of new production processes and new materials. Production cost is also a factor that companies take into consideration during new product development. Lime-based mortars have been extensively used for restoration interventions in Cultural Heritage Monuments and have successfully addressed different performance and compatibility requirements. Recently, different carbon-based nanostructures have been efficiently incorporated in the material matrix so as the restoration material to obtain additional functions, i.e., the ability for self-monitoring. Nevertheless, the manufacturing industries of such materials are typical providers of emitted greenhouse gases in the atmosphere and therefore, cost efficient manufacturing processes and materials with low carbon footprint emissions during their life cycle are essentially needed. The aim of the present article is to investigate the environmental and economic impact in the production process of carbon-nanostructures that will be afterwards incorporated to the restoration material. We present a comparison among five novel modified processes of carbon nanostructures targeted to the specific application in laboratory scale, in terms of manufacturing cost according to the Activity Based Costing methodology, lead processing time and CO2eq emissions according to the PAS2050 standard.

3 - Simulation based optimization for maintenance strategies using Altarica 3.0

Selma Khebbache, Michel Batteux

The maintenance of industrial production systems is one of the major actual challenges, and the management of their maintenances is an important competitiveness factor. In fact a suitable maintenance strategy increases the system availability, and decreases costs due to interventions. Different kinds of maintenance policies can be used: corrective ones to repair the system after failures, preventive ones to maintain the system before failure. Based on a system case study, this work is a contribution to the field of simulation-based optimisation of maintenance strategies. The goal is to plan preventive maintenances according to two objectives: system availability and cost minimisation. Stochastic Discrete Event Simulation model was developed using Altarica 3.0 tool and connected to a Multi-objective optimisation algorithm (NSGAII). Both simulation and optimization modules interact with each other according to an iterative loop. The optimization combines statistics, coming from previous iteration, and the NSGAII algorithm provide to the simulation a new set of parameters for the model (the dates of maintenances), then the outputs of the simulation are performed in a new iteration. The experiments show that the NSGAII based approach achieved the best results although the computation time was relatively high and give more flexibility to the decision maker and give a trade-off between the two objectives.

■ MA-45

Monday, 8:30-10:00 - Virtual Room 45

OR and the Arts, Creativity 2

Stream: OR and the Arts, Creativity
Invited session
Chair: *Gerhard-Wilhelm Weber*
Chair: *Olga Nazarenko*
Chair: *Olabode Adewoye*

1 - Visualizations of discrete equiangular spirals based on similar metallic ratios using Pythagorean theorem and weighted Fibonacci sequences
Shingo Nakanishi

We can investigate several discrete spirals based on Pythagorean theorem and weighted Fibonacci sequences using similar metallic ratios. First, we can propose that some Archimedean or Equiangular spirals by Pythagorean theorem are shown by multiples of slopes of integrals of cumulative distribution function of standardized Laplace-Gaussian distribution. Moreover, the summations of areas of the largest square and the smallest square, that is equal to the twice of the area of the square which is estimated by the hypotenuse based on Pythagorean theorem, are illustrated as the orbit of the spiral of Theodorus. Second, we can visualize the two important combinations about right triangles by Kepler to create the Archimedean spirals or the Equiangular spirals. We can understand that there could be truly divine proportion on the Cartesian coordinates. Third, if we think of the series of Kepler triangles, we can also show you the sequence of Pythagorean theorem based on Fibonacci sequence. From this viewpoint, we can find the weighted Fibonacci sequences about the other similar metallic ratios. To show that, we can calculate the matrices by weighted Fibonacci sequences and these characteristic equations to get eigen values of these matrices. Therefore, we can estimate the eigen values according to various similar metallic ratios. These are shown as the important numbers m and 1-m. the number m multiplied by the number m-1 is the same order about the similar metallic ratios.

2 - A Robust Longitudinal Model for Song Popularity: A Cross-Cultural Study
Enis Kayis, Ahmet Çimen

Usage of new generation music streaming platforms such as Spotify and Apple Music has increased rapidly in the last years. Prediction of a song's popularity is valuable for these firms which in turn translates into higher customer satisfaction thanks to more effective recommendation systems. In this study, we develop a mathematical model to study longitudinal data on song popularity that is designed to be robust across time. The tradeoff between robustness and information gain is controlled via the mathematical model. We investigate the effect of several acoustic and artist related features as well as temporal ones using a dataset that includes individual song's temporal streams and as well as acoustic features of the songs. The results across different countries are compared to analyze how the determinants of song popularity differ across cultures.

■ MA-46

Monday, 8:30-10:00 - Virtual Room 46

Specific Applications of Stochastic Modeling and Simulation in Engineering, Management and Science 1

Stream: Specific Applications of Stochastic Modeling and Simulation in Engineering, Management and Science
Invited session
Chair: *Alireza Goli*
Chair: *Erfan Babaee Tirkolaee*
Chair: *Manuel Ostermeier*

1 - Simulation-based design analysis of multi-period incentive schemes
Sascha Hägele, Alexander Baumeister

To prevent short-term suboptimization, companies are increasingly using long-term manager compensation plans. Opportunistic behavior by managers manifests itself e. g. in book or real accounting policies. However, the optimal design of multi-period incentive systems is not in the core of principal-agent literature. Therefore, a parametric multi-period decision support is presented, that is simulation-based on different long-term incentives to avoid opportunistic managerial behavior. Purely positive incentives such as share-based compensation are used as reference case. They are compared to instruments, that tend to create a more symmetric risk situation with partial loss participation, such as bonus banks and clawback. The modeling is based on a stochastic stock price development according to the geometric Brownian motion as well as a stochastic project success. Due to the complexity, a simulation analysis is used. As one surprising result it is not always advantageous for principals to prevent opportunistic actions of agents due to increasing agency costs. In addition, the benefits of the various methods used in practice vary widely.

2 - A mixed truck and robot delivery approach for the daily supply of customers
Manuel Ostermeier, Andreas Heimfarth, Alexander Hübner

Innovative last-mile logistics solutions are needed to reduce delivery costs, traffic congestion, and pollution in cities. A promising concept in this context are truck-and-robot systems, as they enable significant cost and traffic reduction compared to classic truck deliveries. The system relies on small autonomous delivery robots to cover the last meters to a customer. Existing truck-and-robot concepts to date consider home deliveries by robots, while trucks are only used to transport robots and not for deliveries. This assumption disregards the fact that regular truck deliveries are still needed for some delivery requests, such as for the delivery of bulky items, or for customers who do not accept robots.

Our research addresses this issue and proposes a mixed truck and robot delivery concept in which both robots and the delivery truck can visit customers. Our tailored solution approach is based on a General Variable Neighborhood Search that efficiently solves the routing problem and outperforms existing truck-and-robot routing algorithms. The numerical experiments show that this approach enables cost reductions of up to 43% compared to classical truck deliveries and up to 22% compared to a truck-and-robot system that does not allow deliveries by both truck and robots on the same tour. Further analyses reveal additional benefits of such mixed tours and the robustness of our approach for different problem settings.

3 - Anticipatory Order Picking
Son Tran, Christof Defryn, Rui Jorge Almeida

Order picking describes the process of retrieving a set of products from a warehouse in response to newly incoming customer orders. Deterministic order picking models assume all customer orders to be known at the beginning of the planning horizon. As a result, the application of such models in a dynamic environment is limited to a reactive strategy and ad-hoc decision-making each time new information becomes available.

To mitigate demand uncertainty and improve the efficiency of the picking operations, we explore the idea of anticipatory order picking (AOP). In AOP, expected (but uncertain) customer orders are considered when planning and executing order picking activities. In contrast to the confirmed orders, these expected orders - if picked - are stored in a small buffer zone close to the packing and/or labeling station from which they can be retrieved with very limited travel time.

Extensive simulation experiments revealed the following advantages. First, AOP can provide a better workload balance by relocating peak hour orders during preceding, off-peak time intervals. Second, by picking orders at a time when their marginal travel cost is low, the total travel time and distance are reduced as well as the overall amount of traffic in the warehouse. Third, by better utilizing the pickers' working time, the picking of all confirmed orders can complete earlier.

■ MA-51

Monday, 8:30-10:00 - Virtual Room 51

Optimal Control Theory and Applications 1

Stream: Optimal Control Theory and Applications
Invited session
Chair: *Andrea Seidl*

1 - Smart Products: Liability, Investments in Product Safety, and the Timing of Market Introduction
Herbert Dawid, Gerd Muehlheusser

We analyze the role of product liability for the emergence and development of smart products such as autonomous vehicles (AVs). We develop, and calibrate to the U.S. car market, a dynamic model where a (monopolistic) innovator chooses safety stock investments, the timing of market introduction, and the product price. Inducing higher long-term product safety through a strict (partial) liability rule reduces short-term safety investments and slows down AV market penetration. By contrast, negligence-based liability fosters initial investments without hampering long-term product safety. However, too stringent liability might forestall investments in the development of AVs and their market introduction.

2 - On Sufficient Optimality Conditions for Infinite Horizon Optimal Control Problems
Anton Belyakov

We consider the Seierstad sufficiency theorem in comparison with the Mangasarian and Arrow sufficiency theorems for optimal control problems with infinite time horizon. Both finite and infinite values of the objective functional are allowed, since the concepts of overtaking and weakly overtaking optimality are implied. We extend the conditions under which the Seierstad sufficiency theorem can be applied and provide appropriate examples. The sufficient conditions are shown to be both necessary and sufficient when the Hamiltonian is linear with respect to state and control. We obtain a new form of sufficient optimality conditions in the case when the Hamiltonian is neither concave nor differentiable with respect to control.

3 - The structure of optimal solutions for harvesting a renewable resource
Dmitry Gromov, Thorsten Upmann

In this contribution we consider the problem of optimal harvesting a renewable resource, whose dynamics are governed by a logistic differential equation and the payoff is proportional to the amount of the harvested resource. We consider both the finite and infinite horizon cases and analyze the structure of the optimal solutions depending on the values of system parameters. It is shown that the optimal control profile can have one of three shapes: 1) maximal harvesting effort until the resource depletes, 2) zero harvesting during the initial interval (whose duration is determined by the system parameters and the initial amount of the resource) and a subsequent switch to maximal harvesting effort, and 3) a so-called singular solution that corresponds to an intermediate value of the harvesting effort. The latter scenario realizes only for the infinite horizon case and corresponds to a particular combination of system parameters. In contrast to the former two scenarios, the singular solution corresponds to a sustainable harvesting strategy as it does not lead to complete depletion of the resource. We characterize the conditions under which the singular solution is optimal and present suggestions for designing optimal and sustainable harvesting strategy.

The work of D. Gromov was supported by the Russian Science Foundation (project no. 17-11-01093).

4 - Abnormal Solutions in Reputation Accumulation Problems and Marketing
Andrea Seidl, Gustav Feichtinger, Dieter Grass, Richard Hartl, Peter M. Kort

In the past, abnormal solutions were considered as sign of degeneracy and as not particularly important for relevant applications. In the present talk, we show that this is not the case. In particular, we discuss abnormality in context of marketing and reputation accumulation problems. We find that abnormality can be related to history dependence and occur just due to a simple constraint on the control that makes it impossible to direct the state into a favourable direction. We discuss in this context the concept of a stalling equilibrium where a decision maker has to exert maximum efforts to prevent an unfavourable long run outcome.

■ MA-52

Monday, 8:30-10:00 - Virtual Room 52

EDDA 1

Stream: EURO Doctoral Dissertation Award
Award Competition session
Chair: *Hande Yaman*

1 - Models and Solution Methods for Stochastic Vehicle Routing Problems
Alexandre Florio

This thesis investigates what is known in the transportation literature as stochastic vehicle routing problems (SVRPs). SVRPs arise whenever vehicle routes must be planned, but the full setting where routing is to take place is not known with certainty. The first studied problem is a new SVRP variant, in which the availability of customers for receiving deliveries is uncertain. This new SVRP is motivated by attended home delivery, in particular, the delivery of e-commerce orders.

Next, the focus becomes the classical vehicle routing problem with stochastic demands (VRPSD). The problem is regarded under a priori optimization and optimal restocking. The first contribution is a mixed-integer linear model for the single-vehicle version, which allows solving exactly small problem instances. In addition, a heuristic method to find good quality solutions in larger instances is proposed.

The VRPSD with multiple vehicles is then extensively studied. First, a state-of-the-art branch-price-and-cut algorithm for the VRPSD is introduced. This is the first method that is able to solve instances with few customers per vehicle, which are the most relevant instances concerning the value of stochastic solution. Following that, the VRPSD is considered under probabilistic duration constraints instead of the usual capacity-based constraints. These alternate constraints are more realistic whenever routes must finish within some prescribed time limit (e.g., due to working hours regulations). Under this new set of constraints, the VRPSD becomes considerably more difficult. The problem is solved exactly for the first time by a novel branch-and-price algorithm, which combines different strategies for evaluating route feasibility.

The last contribution is a Bayesian model for the VRPSD with positively correlated demands, along with an optimal restocking policy for this case. This is an important step towards addressing one of the current challenges in stochastic routing: developing models and algorithms that can handle statistical dependence among uncertain parameters.

2 - Set Packing, Location and Related Problems
Mercedes Pelegrín

This work is a study on discrete location and set packing, and their application to different domains. In the first part, set packing formulations are investigated. Set packing problems are a paradigmatic example within Combinatorial Optimization, and have applications in many subfields, including Locational Analysis. The thesis proposes and studies two new variants of a well-known discrete location problem, which are formulated as set packings. The second part is devoted to different combinatorial problems arising in a wide range of disciplines—namely, Computational Biology, Cartography, and Network Analysis—, which are related to discrete location and set packing.

The first part of the dissertation focuses on the polyhedral study of set packing models. An emphasis is placed on deriving valid inequalities, facets and lifting techniques, together with the computational tools that allow to exploit these theoretical results. The main goal is to obtain better mathematical programming formulations for set packing problems. Another objective is to study new discrete location problems arising when additional constraints are considered on user allocation. This part of the dissertation can be divided into three blocks. The first of them concerns general aspects of set packing, including the proof of a new theorem for facet lifting. The other two study particular instances of the set packing arising in the context of Locational Analysis. Namely, two novel variants of the Uncapacitated Facility Location Problem, also known as Simple Plant Location Problem (SPLP), are proposed and studied. More precisely, two previously overlooked scenarios of the SPLP are introduced, namely when users cannot be served by the same center, or when double assignment is considered and some pairs of users must be assigned to the same facility. The common methodology to derive new valid inequalities and facets for these two variants is completed by implementing separation algorithms that allow to incorporate the new inequalities to standard solution techniques. Our computational experience demonstrate the practical relevance of the devised inequalities and algorithms, achieving a significant improvement when compared to a commercial solver or alternative formulations.

The second part of the thesis exposes the interplay between Locational Analysis and other disciplines, and aims at the study of combinatorial problems of these disciplines that are related to the first part. These are haplotyping of diploid organisms, optimal map design, and identification of key members in social networks. For each of these problems, mathematical programming formulations are proposed, possible enhancements are studied, tailored algorithms are designed and implemented, and computational tests are conducted. The methodology would be that customary for this kind of approaches, including proposing decision variables and constraints to model the problem— which is in our case a non-trivial step—, deriving valid inequalities to improve the resulting formulation and possible comparison with other existing models. Furthermore, specific solving techniques are implemented when needed.

In the context of haplotype phasing, we study root graph reconstruction from the graph that encodes genetic consistency relations between a set of individuals. This reconstruction sometimes requires overlooking some of the consistency relations, that is, deleting some edges of the mentioned graph. The combinatorial problem is then to decide which edges to delete so that the root graph reconstruction is allowed while the graph encoding consistency relations is altered as little as possible. Our main contribution consists of disclosing the connection between this problem and the discrete location problems of the first part, and proposing several alternative formulations and different families of valid inequalities for the problem. We explore the relation between formulations and provide both theoretical and computational comparative analysis.

On the other hand, the main goal when tackling map labeling is the automatic design of less ambiguous maps. Different models are proposed, which are inspired by ordered median problems in the context of Locational Analysis. The effectiveness of the proposed formulations is validated through computational tests on maps of the Region of Murcia in Spain. The readability of our solutions significantly improves that of the solutions obtained with other existing models.

Finally, the study of key nodes in a network focuses on adapting the eigenvector centrality measure to the problem of group relevance. Similarly to p-median models, nodes are clustered and each cluster is assigned to the same median, i.e. the most relevant node. In our approach, eigenvector computation is embedded in the clustering procedure. As a result, a mathematical formulation that uncovers the group of key nodes together with their communities is proposed. Modeling this idea with mathematical optimization variables involves highly non-linear equations, which are linearised to produce a mixed-integer linear programming formulation for the problem. Experiments on real-life networks of small size show interesting results that reveal previously unnoticed key members. Our computational experience on larger synthetic networks demonstrates an adequate scalability of the method, which is able to find optimal solutions for networks of hundreds of nodes and thousands of links.

Monday, 10:30-12:00

■ MB-01

Monday, 10:30-12:00 - Bulding A, Amphitheatre

Dynamics and Games 3

Stream: Dynamics and Games
Invited session
Chair: *Alberto Pinto*

1 - Accepting Defective Products and Renegotiating in Collaborative Product Development
Sara Rezaee Vessal, Timofey Shalpegin

We model a two-stage collaborative development process involving a buyer and a supplier in which the buyer can accept an underperforming product after the first stage. This leads to renegotiation in the second stage of product development. We explore the effect of the bargaining power on the development efforts.

2 - Risk aversion in one-sided matching
Tom Demeulemeester, Dries Goossens, Ben Hermans, Roel Leus

Inspired by real-world applications such as the assignment of pupils to schools, the one-sided matching problem studies how a set of agents can be assigned to a set of objects when the agents have preferences over the objects, but not vice versa. For fairness reasons, most mechanisms use randomness, and therefore result in a probabilistic assignment. We study the problem of decomposing these probabilistic assignments into a weighted sum of ex-post (Pareto-)efficient matchings, while maximizing the worst-case number of assigned agents. This decomposition preserves all the assignments' desirable properties, most notably strategy-proofness. For a specific class of probabilistic assignments, including the assignment by the Probabilistic Serial mechanism, we propose a polynomial-time algorithm for this problem that obtains a decomposition in which all matchings assign at least the expected number of assigned agents by the probabilistic assignment, rounded down, thus achieving the theoretically best possible guarantee. For general probabilistic assignments, the problem becomes NP-hard. For the Random Serial Dictatorship (RSD) mechanism, we show that the worst-case number of assigned agents by RSD is at least half of the optimal, and that this bound is asymptotically tight. Lastly, we propose a column generation framework for the introduced problem, which we evaluate both on randomly generated data, and on real-world school choice data from the Belgian cities Antwerp and Ghent.

3 - Learning dynamics against fake news
Alberto Pinto, José Martins

Inspired in Daley-Kendall and Goffman-Newill models, we propose an Ignorant-Believer-Unbeliever rumor (or fake-news) spreading model with the following characteristics: (i) a network contact between the individuals that determine the spread of the rumors; (ii) a value (benefits versus costs) for the individuals who search for truthful information (learning); (iii) an impact measure that assess the risk of believing on the rumor; (iv) an individual search strategy (or learning strategy) based on the probability that an individual searches for truthful information; (v) a population search strategy based on the proportion of individuals of the population who decide to search for truthful information; (vi) a payoff for the individuals that depends on the parameters of the model and the strategies of the individuals. Furthermore, we introduce the evolutionary information search dynamics (or learning dynamics) and study the dynamics of the population search strategies. For each value of searching for information, we compute the evolutionary stable information search strategies (occurring in non-cooperative environments) that are the attractors of the information search dynamics; and the optimal information search strategy (occurring in, eventually forced, cooperative environments) that maximizes the expected information payoff of the population. For rumors that are advantageous or harmful to the population (positive or negative impact), we show the existence of distinct scenarios

■ MB-02

Monday, 10:30-12:00 - Bulding A, Room A5

Flexible shop scheduling problems

Stream: Scheduling and Project Management
Invited session
Chair: *Pierre Lopez*
Chair: *Laurent Houssin*

1 - Logic-based Benders Decomposition for Flexible Job Shop Scheduling with Sequence-Dependent Setup Times
Carla Juvin, Laurent Houssin, Pierre Lopez

The flexible job shop scheduling problem with sequence-dependent setup times is considered. In job shop scheduling, a set of jobs is to be scheduled on a set of machines and each job consists of a set of operations processed following a given route. In the flexible version, each operation can be processed on any machine of a given set. Setup times occur between operations of different jobs sharing the same machine. Several indicators may be considered to measure the performance of a schedule, among makespan, total completion time, total tardiness. A logic-based Benders decomposition approach is proposed to solve the problems under consideration. It consists in dividing the problem into a machine assignment master problem and a classical job shop scheduling subproblem. Mixed-integer programming is used to solve the master problem while the subproblem is tackled by constraint programming. Computational experiments based on benchmark problem instances are reported.

2 - The makespan service level in the stochastic flexible job-shop scheduling problem
Mario Flores Gomez, Stéphane Dauzere-Peres, Valeria Borodin

Classical scheduling problems assume processing times as certain. In real life, this is often not the case as several factors can induce variability in the duration of activities. This talk considers the flexible job-shop scheduling problem with stochastic processing times, represented by independent random variables with known parameters. Contrary to expectation-based criteria widely used to take decisions under uncertainty, the probability of the makespan to be smaller than a predefined value, called makespan service level, is maximized. The stochastic flexible-job shop scheduling is solved by an efficient Tabu Search combined with a Monte Carlo sampling method to handle the makespan probabilistic constraint. Computational experiments are conducted on extended versions of benchmark instances. The numerical results illustrate the impact of key characteristics of the approach and show the relevance of the makespan service level when compared with other criteria of the literature. Perspectives to extend both the proposed approach and the optimization criterion are also discussed.

3 - Time-critical testing and search problems
Ben Hermans, Alessandro Agnetis, Roel Leus, Salim Rostami

In this talk, we introduce a problem in which the state of a system needs to be determined through costly tests of its components by a limited number of testing units and before a given deadline. We also consider a closely related search problem in which there are multiple searchers to find a target before a given deadline. These natural generalizations of the classical sequential testing problem and search problem are applicable in a wide range of time-critical operations such as machine maintenance, diagnosing a patient, and new product development. We show that both problems are NP-hard, develop a pseudo-polynomial dynamic program for the special case of two time slots, and describe a partial-order-based as well as an assignment-based mixed integer program for the general case. Based on extensive computational experiments, we find that the assignment-based formulation performs better than the partial-order-based formulation for the testing variant, but that this is the other way round for the search variant. Finally, we propose a pairwise-interchange-based local search procedure and show that, empirically, it performs very well in finding near-optimal solutions.

■ MB-03

Monday, 10:30-12:00 - Bulding A, Room 3A

Robust and stochastic modeling in logistics, production and warehouse planning

Stream: Specific Applications of Stochastic Modeling and Simulation in Engineering, Management and Science
Invited session
Chair: *Erfan Babaee Tirkolaee*
Chair: *Alireza Goli*
Chair: *Elisenda Molina*

1 - Management of uncertainty in disassembly systems based on stochastic programming
M.-Lounes Bentaha

Unlike assembly systems disassembly ones are characterized by a presence of both several sources of uncertainty and high level of this latter. The main uncertainty sources include demand uncertainty, high variety of end-of-life product quality states, uncertainty of task processing times and presence of hazardous material in the end-of-life products. To guarantee disassembly system efficiency the decision maker has to tackle with these uncertainties at the strategic level (system design), tactical level (system reconfiguration, workload balancing) and operational level (operations scheduling). It is shown in this work that the decision maker can reach such required efficiency in handling disassembly uncertainty by using a stochastic programming based approach. Stochastic programming is particularly used here to model and optimize disassembly systems at the strategic and tactical levels.

2 - A new algorithm for influence maximization
Elisenda Molina, Juan Tejada, Juan Vidal-Puga

Collective action sometimes seems to spring up overnight. However, it is well known that these phenomena do not emerge spontaneously, but are forged through a social network that facilitates the exchange of information and the formation of opinions among individuals. Such processes usually start with a few individuals and gradually spread through the social network and may (eventually) reach a much larger number of individuals. Therefore, it is a fundamental issue, given a social network, to be able to efficiently select groups of network members to initiate the propagation of such collective action. Since the seminal work of Kempe et al. (2003), in which the basic stochastic models of diffusion and the influence maximization problem are formally introduced, this problem has been extensively analyzed and many heuristics have been proposed to tackle it. In this setting, the single discount heuristics (DDH) of Cheng et al. (2009), which has been designed for independent and homogeneous cascade models, results to be an efficient and simple heuristic that can be used as a starting point of other more sophisticated procedures. We propose a generalization of the DDH to no homogeneous cascades, to be used in combination with a more demanding heuristic, which we called Stochastic Deep Search, based on approximating every agent's influence over every other agent in the network.

3 - ProjectManagement: an R package for managing projects
Juan Carlos Gonçalves, Ignacio García-Jurado, Julian Costa

Project management is an important body of knowledge and practices that comprises the planning, organisation and control of resources to achieve one or more pre-determined objectives. In this presentation, we introduce ProjectManagement, a new R package that provides the necessary tools to manage projects in a broad sense, and illustrate its use by examples.

■ MB-06

Monday, 10:30-12:00 - Building Δ, Room Δ103

Mixed Integer Linear Programming for resource allocation

Stream: Mixed Integer Linear Programming
Invited session
Chair: *Rosario Scatamacchia*

1 - Parallel batching with multi-size jobs
Elena Rener, Alessandro Druetto, Erica Pastore

Parallel batch scheduling has many applications in the industrial sector, such as material and chemical treatments, components creation through mold or additive manufacturing, and so on. The number of jobs that can be processed on a machine mostly depends on the shape and dimension of the jobs and of the machine. Literature provides many researches on the topic with several batching criteria however, to the authors knowledge, there is no study that considers batching jobs with multiple size constraints. The work investigates this problem, by considering that the batch capacity cannot exceed the sum of sizes of the jobs composing it, for each dimension (e.g., height and volume). A solution to the problem is generated by a column generation based heuristic. The heuristic first generates a set of the most promising batches through column generation by exploiting dynamic programming for the pricing procedure; then an integer optimal solution is built with the commercial solver CPLEX. The algorithm is further improved with a variable fixing procedure that speeds up the integer solution generation. Experiments are run on instances with several combinations of parameters and results show the impact of the number and type of sizes on computational times and quality of solutions. Some considerations are extended to the problem that also considers incompatible job families.

2 - Mixed Integer Programming Equilibria
Gabriele Dragotto, Andrea Lodi

From a high-level perspective, the subject of this talk encompasses two areas of research: Mixed-Integer Programming (MIP) and Algorithmic Game Theory (AGT). We aim to investigate the essential questions concerning the nature of equilibria for games where (i) the feasible sets of players involve mixed-integer programming sets (e.g., integer programming games) or (ii) an equilibrium can be computed using MIP. Such problems extend to a multi-agent setting the typical family of tasks of the operations research community, for instance, logistics, matching, scheduling, tactical decision making. Within this context, we present some results on the complexity of computing equilibria, some algorithmic ideas, and a new class of valid inequalities. We strongly believe the joint endeavor between AGT and MIP can widen their theoretical understanding and practical impact. Finally, we hope to show how equilibria concepts may provide fair and socially beneficial solutions by being integrated with consolidated resource allocation problems.

3 - On computing Pure Nash Equilibria for the two-player Knapsack Game and Potential Integer Programming Games
Rosario Scatamacchia, Gabriele Dragotto

We consider the two-player Knapsack Game, a non-cooperative and simultaneous Integer Programming Game where two players select items from a common set of items. The selection of an item by a player impacts (negatively or positively) the initial profit of that item for the other player. Thus, given the choices of a player, the other player solves a classic 0/1 Knapsack Problem. Under reasonable assumptions on the input data, we show that the game admits a potential function and so has at least one Pure Nash Equilibrium (PNE). We derive a Mixed Integer Linear Programming formulation to compute the PNE that maximizes the potential function. Then, among all possible pure equilibria, we are interested in finding the best PNE for a certain measure of interest (in particular, we consider the social welfare). To accomplish this task, we propose an enumerative solution approach that combines tools from Integer Programming and Dynamic Programming with concepts from game theory such as the best response dynamics. We also discuss some theoretical aspects of the problem and extensions to other Integer Programming Games with potential functions.

■ MB-21

Monday, 10:30-12:00 - Virtual Room 21

Behavioural impacts from the use of gamified approaches

Stream: Descriptive and prescriptive behavioural OR studies
Invited session
Chair: *Alice H. Aubert*

1 - Side effects of gamification in the context of participatory modeling
Elena Bakhanova, Alexey Voinov, Jaime Garcia, William Raffe

Modeling with stakeholders is one of the collaborative approaches for analysis and decision-making on complex problems. While developing a model together, the participants gain a shared and more in-depth understanding of the problem, however, group interaction and the overall engagement in the process might be challenging. There is an extensive literature on game design (e.g., serious games, management simulators and etc.) that addresses some of the challenges in the context of group learning. In most of the cases either positive or neutral effects were observed, and little attention was given to the possible side effects or unintended consequences of gamified activity. It is important to consider such effects in group settings because different people react in various ways to the overall idea of gamification as well as to the motivational drivers behind the game elements. For example, the risk associated with age or status of participants can become real during the gamified modeling session if senior participants do not feel comfortable interacting with high-tech solutions or not willing to be involved in an activity that is perceived as unserious. Another anticipated risk is connected to a rewards system that, on the one hand, encourages participation with points but, on the other hand, can demotivate those who are not succeeding. In our research we review some of the main gamification approaches used in participatory settings and propose precautions for using them.

2 - Design Gaming for Learning Systems Intelligence in Socio-Emotional Systems
Esa Saarinen, Raimo P. Hämäläinen, J. Tuomas Harviainen, Kata-Riikka Kumpulainen

The tradition of systems thinking games, such as the well-known Beer Game, has focused on the the understanding of dynamics of physical processes. Yet, we also need to have tools to understand the typically invisible complex socio-emotional dynamics of groups and organizations. To address these by systems thinking the concept of Systems Intelligence (SI) was introduced by Saarinen and Hämäläinen in 2004. SI refers to intelligent behavior in the context of complex systems involving interaction and feedback, such as organizations. One can evaluate her competence in SI by the SI test. We used the test to design a card game to learn SI and to make improvements in people's behavior in socio-technical settings. This gamification approach was tested in the field in an extensive intervention study aiming to improve the everyday practice of early childhood professionals. The results suggest that the game sessions did indeed have a positive impact on the participants' engagement towards conversation, increased shared consciousness and made teams' decision processes more efficient. The digital version of the SI card game offers further possibilities to support groups whose members are based in distributed locations, which is an increasing trend today in many industries and often the reality in environmental management. Socio-emotional dynamics also play a key role in group problem solving and participatory decision making and new tools to help stakeholder engagement are needed

3 - Gamified information on objectives: Is learning and range sensitivity of the elicited weight improved?
Alice H. Aubert, Judit Lienert

Gamification and serious games (GSG) are increasingly used in complex multi-objective multi-stakeholder decision processes. In participatory environmental modelling, role-playing simulation games are rather common, but there is a lack of approaches to include stakeholder preferences. GSG should improve participants' experience, and factual and normative learning. The benefits of GSG are yet to be backed with systematic assessment. We will introduce an online gamified interface to inform on objectives to consider when deciding about wastewater management. We designed it based on state-of-the-art gamification literature. We hypothesized that through gamification, learning will improve, and therefore the ranges of objectives will be better considered during weight elicitation in Multi-Criteria Decision Analysis (MCDA). We report on a between participant experiment involving 174 students, split into four treatments (given the two varying factors: gamification vs. no gamification, and original vs. manipulated range). We will present the systematic assessment procedure. We assess whether the online gamified interface effectively (1) improved learning facts, (2) assisted preference construction based on the provided ranges, and (3) provided a positive experience. While gamification was more entertaining than the control treatment, unfortunately, the range insensitivity bias was not overcome, possibly because learning was not increased.

■ MB-22

Monday, 10:30-12:00 - Virtual Room 22

Copositive and completely positive optimization

Stream: Conic Optimization and Related Topics
Invited session
Chair: *Karthik Natarajan*
Chair: *Paula Amaral*

1 - An algorithm of regularization of linear Copositive Problems
Tatiana Tchemisova, Olga Kostyukova

The idea of regularization appears quite naturally and consists of transforming a given optimization problem to an equivalent form where a certain regularity condition is satisfied and therefore the strong duality holds. In the talk, we will describe for these problems a minimal face regularization approach suggested by J.M. Borwein and H. Wolkowicz, and a regularization approach of H. Waki and M. Muramatsu which is based on the facial reduction approach. After, we will present a new regularization algorithm Reg-LCoP, which is based on a new concept of immobile indices suggested in our study of semi-infinite, semidefinite, and copositive problems. We compare algorithm Reg-LCoP with algorithms based on the facial reduction approach and prove that being applied to linear copositive problems, the approach based on the immobile indices permits us to formulate the regularized problem explicitly, and hence the algorithm is more constructive.

2 - Copositivity detection using a DNN decomposition
Paula Amaral, Immanuel Bomze

In this talk we present an algorithm that is based on the decomposition of a matrix in the doubly non-negative cone. The optimization problems that correspond to the copositivity certificate is a quadratic optimization that can be reformulated as a fractional program. Using conic relaxation and an heuristic approach lower and upper bounds can be obtained for this problem and used as a certificate for copositivty/ no copositivity Dimensionality reduction techniques as also reported We test this approach with a collection of test problems.

3 - On Standard Quadratic Programs with Exact and Inexact Doubly Nonnegative Relaxations
Yakup Görkem Gökmen, E. Alper Yildirim

The problem of minimizing a (nonconvex) quadratic form over the unit simplex, referred to as a standard quadratic program, admits an exact convex conic formulation over the computationally intractable cone of completely positive matrices. Replacing the intractable cone in this formulation by the larger but tractable cone of doubly nonnegative matrices, i.e., the cone of positive semidefinite and componentwise nonnegative matrices, one obtains the so-called doubly nonnegative relaxation, whose optimal value yields a lower bound on that of the original problem. We present a full algebraic characterization of the set of instances of standard quadratic programs that admit an exact doubly nonnegative relaxation. This characterization yields an algorithmic recipe for constructing such an instance. In addition, we explicitly identify three families of instances for which the doubly nonnegative relaxation is exact. We establish several relations between the so-called convexity graph of an instance and the tightness of the doubly nonnegative relaxation. We also provide an algebraic characterization of the set of instances for which the doubly nonnegative relaxation has a positive gap and show how to construct such an instance using this characterization.

4 - An Alternative Perspective on Copositive and Convex Relaxations of Nonconvex Quadratic Programs
E. Alper Yildirim

We study convex relaxations of nonconvex quadratic programs. We identify a family of so-called feasibility preserving convex relaxations, which includes the well-known copositive and doubly nonnegative relaxations, with the property that the convex relaxation is feasible if and only if the nonconvex quadratic program is feasible. We observe that each convex relaxation in this family implicitly induces a convex underestimator of the objective function on the feasible region of the quadratic program. This alternative perspective on convex relaxations enables us to establish several useful properties of the corresponding convex underestimators. In particular, if the recession cone of the feasible region of the quadratic program does not contain any directions of negative curvature, we show that the convex underestimator arising from the copositive relaxation is precisely the convex envelope of the objective function of the quadratic program, strengthening Burer's well-known result on the exactness of the copositive relaxation in the case of nonconvex quadratic programs. We also present an algorithmic recipe for constructing instances of quadratic programs with a finite optimal value but an unbounded relaxation for a rather large family of convex relaxations including the doubly nonnegative relaxation.

■ MB-23

Monday, 10:30-12:00 - Virtual Room 23

Emerging Trends in Derivative-free Optimization

Stream: Derivative-free Optimization
Invited session
Chair: *Ana Luisa Custodio*
Chair: *Lindon Roberts*

1 - Large-scale Derivative-free Optimization Using Subspace Methods
Lindon Roberts, Coralia Cartis

In existing techniques for model-based derivative-free optimization, the computational cost of constructing local models and Lagrange polynomials can be high. As a result, these algorithms are not as suitable for large-scale problems as derivative-based methods. In this talk, I will discuss a model-based derivative-free algorithm based on exploration of random subspaces, its worst-case complexity bounds, and some numerical results.

2 - Dimensionality Reduction Techniques for Global Optimization Via Random Subspace Embeddings
Adilet Otemissov, Coralia Cartis, Estelle Massart

In an attempt to improve the scalability of global optimization problems, we propose a general random subspace algorithmic framework, which tackles the (high-dimensional) global optimization problem by repeatedly and possibly adaptively solving reduced subproblems with the domains restricted to be along randomly embedded low-dimensional subspaces. We analyse the convergence of the proposed framework for Lipschitz continuous functions using tools from conic integral geometry and random matrix theory. We then particularise the framework and analysis for the class of functions with low effective dimensionality, which are constant along an (unknown) linear subspace and only vary over the effective (complement) subspace. We show that for these functions the convergence could potentially be exponentially better and that, under certain assumptions, it does not depend on the ambient dimension. Our numerical experiments on functions with low effective dimensionality illustrate two things: 1) the improved scalability of the framework when coupled with state-of-the-art global — and even local — optimization solvers for the subproblems 2) the ability of the framework to effectively estimate the (initially unknown) effective dimensionality of the objective function.

3 - Performance Improvement Strategies in Direct Search for Multiobjective Optimization
Carmo Bras, Sérgio Tavares, Ana Luisa Custodio

Direct Search has been successfully used in multiobjective optimization, allowing to compute good quality approximations to the complete Pareto front of a given problem, for local and global derivative-free optimization. These algorithms have a well-supported convergence analysis and have proved to be competitive with other classes of multiobjective optimization solvers, not only in academic test sets, but also in real applications.

The algorithmic structure of a direct search method is organized in a search step and a poll step, performed after the selection of an iteration center. Different strategies can be used for this center selection, and parallel approaches can allow the selection of more than one iteration center at a time. Minimizers of surrogate models, built by reusing points already evaluated, can also enhance the numerical performance of these methods.

In this work, we detail the previous strategies and present numerical results that support their value, both in an academic test set and in a chemical engineering application.

4 - Using First-order Information in Direct MultiSearch
Ana Luisa Custodio, Roberto Andreani, Marcos Raydan

Derivatives are an important tool for single-objective optimization. In fact, it is commonly accepted that derivative-based methods present a better performance than derivative-free optimization approaches. In this work, we will start by showing that the same does not apply to multiobjective derivative-based optimization, when the goal is to compute an approximation to the complete Pareto front of a given problem.

The competitiveness of Direct MultiSearch (DMS), a robust and efficient derivative-free optimization algorithm, will be stated for derivative-based multiobjective optimization problems. Derivatives will then be used to prune the positive spanning sets considered at the poll step of the algorithm, highlighting the role that ascent directions, that conform to the geometry of the nearby feasible region, can have when computing approximations to the entire Pareto front of a given multiobjective optimization problem. This new variant of DMS, which prunes the poll set of directions, but that at some iterations considers its enrichment with ascent directions, shows to be competitive not only with derivative-based solvers but also with the original implementation of DMS.

■ MB-24

Monday, 10:30-12:00 - Virtual Room 24

Consensus-Based Global Optimization

Stream: Global Optimization
Invited session
Chair: *Claudia Totzeck*

1 - From particle swarm optimization to consensus based optimization: stochastic modeling and mean-field limit
Sara Grassi

In this talk we will introduce a continuous description based on stochastic differential equations of the popular particle swarm optimization (PSO) process for solving global optimization problems and derive in the large particle limit the corresponding mean-field approximation based on Vlasov-Fokker-Planck-type equations. The disadvantage of memory effects induced by the need to store the local best position is overcome by the introduction of an additional differential equation describing the evolution of the local best. A regularization process for the global best permits to formally derive the respective mean-field description. Subsequently, under a small inertia limit, we consider the related macroscopic hydrodynamic equations that clarify the relationship with the recently introduced consensus based optimization (CBO) methods. With several numerical examples we will illustrate the mean field process, the small inertia limit and the potential of this general class of global optimization methods. This is a joint work with L.Pareschi.

2 - Derivative-free Bayesian inversion using multiscale dynamics
Urbain Vaes

Inverse problems are ubiquitous because they formalize the integration of data with mathematical models. In many scientific applications the forward model is expensive to evaluate, and adjoint computations are difficult to employ; in this setting derivative-free methods which involve a small number of forward model evaluations are an attractive proposition. Ensemble Kalman based interacting particle systems (and variants such as consensus based and unscented Kalman approaches) have proven empirically successful in this context, but suffer from the fact that they cannot be systematically refined to return the true solution, except in the setting of linear forward models. In this presentation, we propose a new derivative-free approach to Bayesian inversion, which may be employed for posterior sampling or for maximum a posteriori (MAP) estimation, and may be systematically refined. The method relies on a fast/slow system of stochastic differential equations (SDEs) for the local approximation of the gradient of the log-likelihood appearing in a Langevin diffusion. Furthermore the method may be preconditioned by use of information from ensemble Kalman based methods (and variants), providing a methodology which leverages the documented advantages of those methods, whilst also being provably refineable. We define the methodology, highlighting its flexibility and many variants, provide a theoretical analysis of the proposed approach, and demonstrate its efficacy numerically.

3 - Recent advances in consensus-based global optimization
Claudia Totzeck

In this talk we give an overview of recent advances in the context of consensus-based global optimization schemes. Since the publication of the original scheme many variants were proposed to improve the performance for high-dimensional problems as for example arising in machine learning. Other variants enlarge the scope of applications by incorporating constraints or global best information. The talk aims to be an introduction into the topic of the session.

4 - Consensus-based optimization methods converge globally in mean-field law
Massimo Fornasier

In this talk we review consensus-based optimization (CBO), which is a metaheuristic derivative-free optimization method that can globally minimize nonconvex nonsmooth functions and is amenable to theoretical analysis. Based on an experimentally supported intuition that CBO performs a gradient descent on the convex envelope of a given objective, we show a novel technique for proving the convergence to the global minimizer in mean-field law for a rich class of objective functions. Our results unveil internal mechanisms of CBO that are responsible for the success of the method. Furthermore, we improve prior analyses by requiring minimal assumptions about the initialization of the method and by covering objectives that are merely locally Lipschitz continuous. As a by-product of our analysis, we establish a quantitative nonasymptotic Laplace principle, which may be of independent interest.

■ MB-25

Monday, 10:30-12:00 - Virtual Room 25

Stochastic dominance in stochastic optimization

Stream: Stochastic and Robust Optimization
Invited session
Chair: *Milos Kopa*

1 - Multicriteria Crypto Portfolio optimization based on preference rules, expected return and risk measure
Audrius Kabasinskas, Kristina Sutiene, Milos Kopa, Karel Kozmík

This paper introduces multicriteria crypto portfolio optimization problem based on preference rules, expected return and risk measure. Many researches suggest that crypto-currencies nowadays are extremely volatile, risky and potentially profitable instruments for investment. Moreover, they usually are treated as separate class of assets and require special analytical techniques. Stochastic dominance preference rules based on empirical, skewed textitt, NIG, hyperbolic and $alpha$-stable probability distributions are developed and incorporated into portfolio optimization problem. Moreover, various multicriteria decision making techniques are used to test the robustness of model proposed.

2 - Robust approaches in portfolio optimization with stochastic dominance
Karel Kozmík, Milos Kopa

We use modern approach of stochastic dominance in portfolio optimization, where we want the portfolio to dominate a benchmark. Since the distribution of returns is often just estimated from data, we look for the worst distribution that differs from empirical distribution at maximum by a predefined value. First, we define in what sense the distribution is the worst for stochastic dominance. We derive a reformulation for robust second order stochastic dominance and find the worst case distribution as the optimal solution of a non-linear optimization problem. Then we derive programs to maximize an objective function over the weights of the portfolio with robust stochastic dominance in constraints. We consider robustness in returns for second order stochastic dominance. We apply all the derived optimization programs to real life data, specifically to returns of assets captured by Dow Jones Industrial Average, and we analyze the problems in detail using optimal solutions of the optimization programs with multiple setups. The portfolios calculated using robustness in returns turned out to outperform the classical approach without robustness in an out-of-sample analysis.

3 - Coupled and Decoupled Stochastic Dominance Induced by Multistage Quadratic Optimization
Maria Merino, Unai Aldasoro

Stochastic Dominance is a prominent risk averse functional in stochastic optimization that aims to reduce the right tails in minimization problems. Most of the existing strategies in this context consider linear function models. However, many real world applications such as production planning, scheduling and engineering include quadratic terms. We present two novel approaches for the incursion of quadratic terms based on Expected Conditional Stochastic Dominance measures. First, a combined mixed linear-quadratic dominance labelled Coupled Stochastic Dominance. Second, a component-wise separated dominance labelled Decoupled Stochastic Dominance. The resulting quadratically constrained mixed-integer multistage stochastic quadratic problems are computationally expensive and the state-of-the-art solvers are not competitive. A primal decomposition based matheuristic algorithm is proposed. A pilot case is used to illustrate the risk analysis and validate the proposed algorithm efficiency.

4 - Multistage stochastic dominance: an application to pension fund management
Milos Kopa, Sebastiano Vitali, Vittorio Moriggia

A pension fund manager typically decides the allocation of the pension fund assets looking for a long-term sustainability. Many Asset and Liability Management models in the form of multistage stochastic programming problem have been proposed to help the pension fund manager to define the optimal allocation given a multi-objective function. The recent literature proposes univariate stochastic dominance constraints to guarantee that the optimal strategy is able to stochastically dominate a benchmark portfolio. In this work we extend previous results (i) considering alternative types of multivariate stochastic dominance that appear more suitable in a multistage framework, (ii) proposing a way to measure the economic cost of introducing stochastic dominance constraints, (iii) proposing a sort of augmented stochastic dominance through a safety margin. Numerical results show the difference between the alternative ways to interpret and apply the multivariate stochastic dominance. These results are evaluated thanks to the proposed economic cost of the stochastic dominance constraints and either in presence or not of a safety margin.

■ MB-26

Monday, 10:30-12:00 - Virtual Room 26

Processes and techniques for implementing decision analysis

Stream: Decision Analysis and Decision Analytics
Invited session
Chair: *Pavlos Delias*

1 - Risk Assessment and Optimal Scheduling for Serial Projects
Zixuan Zhang, Michail Chronopoulos, Dimitrina Dimitrova, Ioannis Kyriakou

The deregulation of many industries and the increasingly uncertain economic environment have made project scheduling a particularly challenging task and increased the need for techniques that facilitate efficient risk management. Therefore, in this paper, we take the perspective of a private firm that contemplates the capacity expansion of an existing project in discrete stages, and develop a framework for: i. assessing the risk of multi-staged capacity expansion; and ii. optimising the sequence of stages. Assuming that the duration of each stage follows a general probability distribution and that the firm faces output price uncertainty, we derive the distribution of the project's present value (PV), as well as risk measures, such as value at risk (VaR) and conditional VaR (CVaR). Thus, we analyse the impact of duration variability on the VaR and CVaR of the project's PV and demonstrate its implications for the stochastic project scheduling problem. Additionally, we analyse the trade-off between expected PV maximisation and risk minimisation under different sequences of stages, thereby deriving the optimal sequence for both risk-neutral and risk-averse investors. Contrary to the existing literature, results indicate that both the duration variability of each stage and attitudes toward risk can have a significant impact on the optimal schedule of a serial project, and, interestingly, that a higher duration variability is not necessarily harmful, even for risk-averse investors.

2 - Decision making with incomplete preferences: How omitting objectives affects identifying the most promising alternative
Sara Abdeen, Florian Methling, Rüdiger von Nitzsch

Research has shown that decision makers omit a significant number of their objectives when making a decision. As a result, several methods have been proposed to help decision makers generate a more complete set of objectives. This study builds on these efforts. It examines the question of how an incomplete set of objectives affects identifying the most promising alternative. We answer this question using a unique dataset of 945 high-quality decisions. These decisions were developed by students using the decision-skills and training tool entscheidungsnavi.de/en. The tool guides students in a step-by-step process and supports high quality decisions by using value-based thinking, multi-attribute utility theory, and debiasing methods throughout the process. We found that omitting objectives significantly reduces the chances of identifying the most promising alternative. Neglecting only one objective is sufficient to mislead more than one in four decisions. The analysis of the relative weights of the objectives shows that it is particularly important to identify objectives of higher preferences. Thus, these results demonstrate the importance of methods and studies that support decision makers to identify their personal objectives.

3 - The implementation of the multicriteria analysis in the location of the investments.
Vasiliki Charalampidou

In the current pandemic emergency and post-economic crisis period, the expansion of factors and their optimal combination aimed at restructuring the production base is the most serious challenge in Greece. By reviewing the recent trends in spatial planning and redefining the conceptual arrangement, the research question is how investments are located and whether they take full advantage of the available resources or not. Consequently, the objective is to develop a multi-criteria method that is used to identify and select the appropriate investment location based on certain criteria that are weighted differently depending on the type of investment. The application of multi-criteria methodology (AHP) in two case studies, existing and proposed investment, evaluated in terms of their alternative locations. The conclusions were properly drawn by analysing the way of influence of stakeholders such as central government, investors and local community in the planning process. The final siting decision requires several other decisions in which the opinions of the above groups of stakeholders must be adequately considered. Thus, the developed methodology can be used by and for all, focusing on the planning criteria and their prioritisation. For further research, the process and conditions under which other Southern Mediterranean countries locate their investments could be explored.

4 - Assessment and Improvement Undergraduate Education Environment Satisfactory Development Quality
Vivien Y.C. Chen

The increase in the competitiveness of a globalized university education inevitably forces universities to re-examine the evaluation of the teaching and learning equipment, space environment, and the faculty and software capabilities of hardware and software, in order to increase its competitiveness in the global undergraduate education environment. However, a successful undergraduate education environment depends on the development of appropriate systems. Unlike previous multiple attributes decision-making (MADM) methods that assume the criteria are independent, we propose a novel hybrid model, combining a Decision Making Trial and Evaluation Laboratory (DEMATEL) and Analytical Network Process (ANP) method called DANP, which addresses the dependent relationships between the various criteria to better reflect the real-world situation. At the same time, instead of ranking the alternatives, we apply a modified grey relation method to select and improve the criterion-gaps to the aspiration levels. To demonstrate the usefulness and effectiveness of the proposed model, we use data from a China university.

■ MB-27

Monday, 10:30-12:00 - Virtual Room 27

E-Fulfillment

Stream: Analytics in Service Management
Invited session
Chair: *Charlotte Köhler*

1 - Demand Management for Attended Home Deliveries - A Literature Review
Katrin Waßmuth, Charlotte Köhler, Niels Agatz, Moritz Fleischmann

With the continuing boom in e-commerce and the growing number of online ordering options, home delivery services are becoming increasingly more important. A particular challenge from a logistics perspective are attended home deliveries, which require the customer to be present when the purchased goods are delivered. For these types of deliveries, the retailer and customer usually agree on a specific time window for order delivery. Carefully matching fulfillment capacity and demand is important to ensure cost-efficient and reliable delivery operations. We define demand management in the context of attended home delivery as the assortment planning of the offered delivery service during the booking process to achieve operational efficiency while meeting service requirements. In this presentation, we introduce demand management concepts and differentiate them according to their service offering and pricing levers, as well as to the decision sequence with respect to the fulfillment process. We provide an overview of the current state of research in this area and group and review the literature according to this framework. We also provide insights into established and innovative delivery services in practice. Finally, we discuss research gaps and future directions for demand management in delivery services.

2 - Dynamic Time Slot Management with Uncertain Basket Sizes
Liana van der Hagen, Niels Agatz, Remy Spliet

Online grocery retailers typically let customers choose a delivery time slot to receive their groceries. To provide a reliable delivery service, the retailer wants to only accept customer orders that are feasible given the fulfillment capacity (i.e., vehicles). At the same time, e-grocers often let customer already reserve a time slot before they have filled their order basket. This leads to uncertainty about the required capacity when evaluating the feasibility of a certain time slot offering. To add to this uncertainty, many e-grocers allow customers to change their order basket at any time before the cut-off time. Time slots that were feasible at the time of order placement, may later become infeasible. Consequently, it may happen that the capacity turns out to be insufficient to fulfill all accepted orders during the time slots chosen by the customers. We study the impact of this uncertainty on the delivery schedule for the final set of orders. Additionally, we study the effect of different strategies to deal with this uncertainty.

3 - The Value of Data in Home Delivery
Charlotte Köhler, Jan Fabian Ehmke, Ann Campbell

Home delivery services require the attendance of the customer during delivery. Hence, retailers and customers mutually agree on a delivery time window in the booking process. In this presentation, we investigate the value of historical booking data in the decision of whether to accept a customer request for a particular time window in an online booking process to maximize the retailer's profit. We propose a sampling approach to assess the impact of the current request on route efficiency and the ability to accept future requests to increase the retailer's profit. In particular, we introduce an approach to determine the amount and form of booking data that is most beneficial in the retailer's acceptance decision. We apply these techniques to data from an online grocer in Germany.

■ MB-28

Monday, 10:30-12:00 - Virtual Room 28

Data Science and Analytics - Methodology I

Stream: Data Science and Analytics (contributed)
Contributed session
Chair: *Cheolsoon Park*

1 - Geometric multidimensional scaling for multidimensional data visualization
Gintautas Dzemyda, Martynas Sabaliauskas

Data visualization is an integral part of data science along with statistics, pattern recognition, machine learning, artificial intelligence, and data mining. Multidimensional scaling (MDS) is one of the most popular methods for dimensionality reduction and visual representation of multidimensional data for human decision. MDS minimizes multiextremal stress function, dependent on coordinates of data points in a lower dimensionality. A new idea (Geometric MDS) has been discovered to minimize the stress so that the step size and direction forward the minimum of the stress function are found analytically without reference to the analytical expression of the stress function, numerical evaluation of its derivatives and the linear search. It is proved that the direction coincides with the steepest descent direction, and the analytically found step size ensures almost the optimal step in this direction. The discovered option to minimize the stress function is examined, including the global minimization of the stress. According to the experiments, Geometric MDS gives better results as the stress minimization using majorization (SMACOF version of MDS). The advantage of Geometric MDS is that it uses the simplest stress function, and there is no need for its normalization depending on the number of data points and the scale of proximities. This research has received funding from the Research Council of Lithuania (LMTLT), agreement No S-MIP-20-19.

2 - Redundancy in big data: towards a trade-off between convergence and performance
Christian Colot

The explosion of digital data has led to very promising opportunities to leverage it for decision-making. However, a key challenge is to deal with the redundancy issue that might arise among extracted features. This redundancy might indeed lead to select a sub optimal model and also to slow down the convergence of the algorithm. In the present empirical study, we compare the performance of a recent variation of Random Forest namely Essence Random Forest to Gradient Boosting for churn prediction within a telephone company. In particular, this case study includes multiple extracted features from unstructured data with a high level of redundancy. Our results highlight that, without any time constraint, Gradient Boosting reaches a higher classification performance. However, Essence Random converges approximately four times faster than Gradient Boosting to its best performance. Notably, the latter method overtakes the former after 2.7 times the time needed for Essence Random Forest to offer its best result. Overall, these results indicate that the choice of the algorithm depends on the importance of time in the context. What is more, a hybrid combination of both algorithms might be considered as future work as the key mechanism behind Essence Random Forest i.e. a weighted random sampling of features according to redundancy might be implemented in Gradient Boosting. This hybrid combination might potentially speed up the convergence of Gradient Boosting.

3 - A machine learning approach to verify the effectiveness of multi-parameter evolutionary optimization algorithms
Christos-Georgios Xanthopoulos, Pantelis Lappas, Manolis Kritikos

Evolutionary optimization algorithms are biologically-inspired and population-based meta-heuristic algorithms for solving NP-hard problems in a reasonable computation time. Algorithms such as the Genetic Algorithm aim at combining population initialization methods, parent selection, crossover and mutation operators to find near-optimal solutions. In general, the operators and the values related to several parameters such as the crossover percentage, the population size, the number of generations and so on should be carefully picked to produce reliable, fast, and close-optimal results. In addition to this, as the size of the dataset is increased, there is no a unique combination of operators and parameters' values that can guarantee the quality of the results. The purpose of this work is to model the stochastic nature of evolutionary optimization algorithms by applying machine learning algorithms and data science practices. Computational results obtained are explored in depth so as to recognize patterns and determine how the selection of parameters and operators affects the quality of computational results. Several datasets for the Travelling Salesman Problem, as well as a list of many operators will be used to verify the effectiveness of the Genetic Algorithm, whereas several graphical presentation formats will be provided to convey meaningful insights into the problem.

4 - Improved Anomaly Scoring for Anomaly Detection Using Auto Encoder based Unsupervised Learning from Unlabeled Data
Cheolsoon Park, Jun-Geol Baek

Auto encoder is one of the most popular methods of unsupervised deep learning in anomaly detection. Auto encoder utilizes the reconstruction error of the given input as an anomaly score for anomaly detection. This assumes that reconstruction error of abnormal sample is larger than normal sample. However, this assumption has a problem under the following conditions: 1) Unsupervised learning is required from unlabeled data, 2) Train data includes both normal and abnormal samples, 3) Given sufficient learning capacity and time, abnormal samples can also be generalized. In this case, as abnormal samples become generalized, reconstruction errors of abnormal samples decrease. As a result, it becomes difficult to distinguish between normality and anomaly. To overcome this problem, this paper proposes an improved anomaly scoring method, which not only makes a clear distinction between normality and anomaly but also improve accuracy of anomaly score. This improved anomaly score reflects reconstruction error not from the early stopped epoch but from all trained epochs. Several experiments on image data demonstrate that the proposed method overcomes the problem and increases capability to detect anomaly using auto encoder based unsupervised learning from unlabeled data.

■ MB-29

Monday, 10:30-12:00 - Virtual Room 29

Analytic Hierarchy Process

Stream: AHP/ANP
Invited session
Chair: *Masahiro Inuiguchi*

1 - Advantages of maximizing minimum range approach to the interval weight estimation under a crisp pairwise comparison matrix
Shigeaki Innan, Masahiro Inuiguchi

In the Analytic Hierarchy Process (AHP), the geometric mean (GM) method and the eigenvalue (EV) method are widely used for weight estimation. Those are based on minimization of errors. On one hand, the interval AHP estimating interval weights is proposed from the viewpoint that human evaluation is vague. The original interval weight estimation method by minimizing the sum of widths fails to express the vagueness of decision maker's evaluation. Recently, the maximizing minimum range (MMR) approach proposed for obtaining wider estimated interval weights. As MMR approach is a meta method, it is used under any evaluation function of interval weights. MMR approach is useful for estimating widths when center values are estimated by GM and EV methods. We call those G-MMR and E-MMR. Advantages of G-MMR and E-MMR over other interval weight estimation method and GM and EV methods in ranking alternatives are shown when interval weights express well the decision maker's evaluation. However, it was not clear whether the MMR approach to the width estimation works better than the simple application of the evaluation function of interval weights. In this study, we demonstrate the superiority of the MMR approach to the width estimation against the simple application of the evaluation function. We show that advantages of G-MMR and E-MMR are remarkable when total scores of alternatives are similar. The experimental results show that the sum of widths performs better than the sum of deviations.

2 - Decision Analysis with Non-unique Solutions in Interval AHP
Masahiro Inuiguchi, Akiko Hayashi, Shigeaki Innan

The Analytic Hierarchy Process (AHP) is well used decision tool under multiple criteria, providing a method for estimating criteria weights from a pairwise comparison matrix (PCM). The PCM given by a decision-maker is often inconsistent. In this approach, inconsistencies are considered errors, and weights are estimated as real numbers by minimizing the sum of errors. On one hand, in the interval AHP, inconsistencies are supposed to come from human vague evaluations, and normalized interval weights are estimated from a PCM. However, it is known that the most appropriate normalized interval weights are not determined uniquely due to the weakness of the normality condition of interval weights. This non-uniqueness has been resolved by imposing an additional condition, the sum of center values is one. In this paper, we propose a method for decision analysis fully considering the non-uniqueness. In the approach, two uncertainties should be treated: one is the imprecision expressed by normalized interval weights and the other is the ambiguity coming from the non-uniqueness of the solution of the estimation problem. We apply the robust analysis for ranking alternatives. As this approach is too passive, we propose an active approach treating the imprecision of normalized interval weights by maximin principle and the ambiguity from non-uniqueness by parametric analysis. We show a simple algorithm for finding break-even points between alternatives and an example.

3 - A Fuzzy AHP approach to prioritize factors affecting Collaboration among stakeholders of a public-private partnership
Amit Gupta

Purpose: This paper presents decision making model for prioritizing the factors influencing collaboration among the partners of public-private partnership in a public hospital outsourcing radiology services. The success of PPP in radiology setup is dependent on collaboration among physicians-hospital-vendor triad. PPPs are complex to manage; there is demonstrable need for structured collaboration. Methodology: This study applies detailed triangular Fuzzy AHP process as MCDM tool. Collaboration is the goal and ten factors affecting collaboration are considered as criteria. The factors are Contribution, Functional Interaction, Integration, Feedback Mechanism, Objective, Performance, Commitment fulfillment, Transparency, Opportunism, and Control mechanism. Ten experts filled questionnaires for doing pair-wise comparison. Normalized weights to each factor from each respondent were calculated. A final normalized ranking was derived by taking an average of individual weights by all the experts. Value: Identification of the factors affecting collaboration; extending Fuzzy AHP in healthcare; assignment of preferential rankings to various factors; establishing inputs for making a successful PPP Findings: "Performance" rated most important factor, highlighting the relevance of designing economically viable project. "Opportunism" rated least important as shirking responsibilities and taking undue advantage of situations is not really expected at such levels.

■ MB-30

Monday, 10:30-12:00 - Virtual Room 30

Information Systems and OR

Stream: Information Systems and Software for OR
Invited session
Chair: *Andrea Bernardi*

1 - Forest ecosystem management integrating spatial optimization - an approach in Portugal.
Liliana Ferreira, Alexandra Baptista, Miguel Constantino, Isabel Martins, Susete Marques, Jose Borges, Vladimir Bushenkov

Ecosystem management planning demand for innovative decision support tools and represent a challenge to researchers and stakeholders. This research aims at presenting models as part of an integrated approach that may be used into decision support methods and tools to help stakeholders select forest ecosystem management plans and corresponding ecosystem services and products to be marketed. This research intends to present mixed integer programming models that will provide decision spaces for further multicriteria analysis. Spatial optimization is considered through the incorporation of concerns about wildfire resistance or constraints on clearcut and core area or vegetation patches that are relevant to biodiversity. To perform trade-offs analysis between forest-based products and services Pareto frontier approaches are used. This research is applied to the Zona de Intervenção Florestal (ZIF) de Paiva and de Entre-Douro e Sousa (ZIF_VS) that is located in northwestern Portugal.

2 - A risk-based approach to econonomic viability of baseload gas-fired power plants in an energy transition scenario: a study case for Brazil
Catharina Hollauer

The Brazilian Electricity Sector has undergone for considerable reforms and advanced significantly on energy procurement policies, aiming to ensure energy security and reliability for consumers, at reasonable costs. Attracting investments to the sector plays a decisive role and, in the Brazilian Power Sector, it was done by introducing electricity bidding mechanisms to simulate a competitive contracting environment with rules and conditions that enable risk mitigation and stable return guarantee. Through the auction bidding mechanism agents tend to assume higher risks in exchange for higher revenue. Therefore, a better understanding of the intrinsic risks in the project and parameters setting brings valuable information to the power purchase agreement contract. On an environment where natural gas arises as a highly attractive energy source, combined-cycle and gas-fired power plants become an efficient option to guarantee energy supply, especially during peak load hours on electricity markets with high penetration of renewable energy sources. The study intends to present a study case in the brazilian power sector, as a look into the future for many other countries, pointing out the potential constraints and effects that could be faced due to renewable energy penetration growth. Therefore, the article develops a study case, for a base load gas-fired power plant, analyzing the influence of the auction parameters setup on long term contracts incentives considering Brazilian

3 - Multi-objective supply chain optimization in personalized healthcare
Andrea Bernardi, Niki Triantafyllou, Thanasis Antonakoudis, Matthew Lakelin, Nilay Shah, Maria Papathanasiou

Chimeric Antigen Receptor (CAR) T cell therapies utilize T cells taken from a patient's blood and engineered to express the Chimeric Antigen Receptor (CAR), which make them capable of targeting cancer cells [1]. To date, four commercial products have been approved by the U.S. Food and Drug Administration (FDA) and three of them are also approved by the European Medicines Agency (EMA) [2]. Unlike batch produced pharmaceuticals, CAR T cell therapies use patient cells as the raw material and this translates into manufacturing lines and distribution nodes occupied by a single therapy, posing hurdles to the design of robust and responsive networks. The predicted rise of patient number, and the short shelf-life of these therapeutics pose additional challenges in coordinating manufacturing, storage and distribution [3]. In this work, we present a Mixed Integer Linear Programming model for the optimal design of a supply chain network under different demand scenarios. The problem is formulated as multi-objective optimization aiming to minimize the average therapy cost (ATC) and the average therapy return time (ATRT). Our results show how the trade-off between ATC and ATRT depends both on the total annual demand and on the demand profile. Also, the impact of manufacturing time on the supply chain network is discussed. Ref. [1] Levine et al, Mol Ther-Methods Clin Dev, 4, 92-101, 2017. [2] Mullard, Nat Rev Drug Disc, 20, 166 (2021) [3] Griffiths & Lakelin, PCI services, 2018.

■ MB-31

Monday, 10:30-12:00 - Virtual Room 31

Fuzzy Multicriteria Optimization: Methods and Applications

Stream: Multiobjective Optimization
Invited session
Chair: *Manuel Díaz-Madroñero*
Chair: *Mariano Jimenez-Lopez*

1 - Optimality conditions for efficiency in multiobjective fuzzy programming problems
Beatriz Hernández-Jiménez, Rafaela Osuna-Gómez, Yurilev Chalco-Cano, Gabriel Ruiz-Garzón

We consider a fuzzy multiobjective problem with p gH-differentiable objectives defined in Rn. Based on a new p-dimensional stationary solution definition given we obtain neccesary optimality conditions for efficiency that are very simple in order to compute them in an algorithm. And a new generalized convexity notion is given in order to obtain sufficient optimality conditions for this problem. The results obtained generalize the ones that exist in the literature in several aspects. This generalization is reached primarly since our results consider p-dimensional functions instead of scalar functions and they are defined for n variables instead of only one variable. Futhermore, it has been proved that the differentiability notion used is less restrictive than those used in the literature.

2 - Some ranking methods based on weight learning
María Luisa Martínez, Esther Dopazo

The problem of ranking a set of candidates according to different competencies is a critical task in many fields such as human resource management, product selection, and recommender systems, among others. Certain complexities that appear in these problems are the large number of candidates, uncertainty or incomplete information, time pressure, etc. In this context, it is proposed a ranking method that learns from the evaluations relative to limited subsets of candidates given by different experts. Our first goal is to derive the priority weight vector that best summarizes expert data (used as training examples), that may be inaccurate and conflicting. This learning module is constructed on an OWA operator and different distance measurements to simulate different aggregation procedures. The resulting optimization problems are solved using GP techniques. The candidates are then ranked using an OWA operator and the obtained priority vector. Finally, some measures are provided to analyze the quality of the induced ranking from data given by the experts.

3 - Fuzzy De Novo approach with variable budget for aggregated production planning problem
Manuel Díaz-Madroñero, Mariano Jimenez-Lopez, Josefa Mula

Different approaches to solving multi-objective optimisation models based on the De Novo method have been published in the literature. But, to the best of our knowledge, none of them has considered that the available budget could vary. By modelling this budget as a fuzzy set, we also obtain the optimal values of the objectives as fuzzy sets. From there we build a fuzzy programming model that gives us a solution that is a good balance between the budget and the target values in the context of an aggregated production planning problem. This work was supported by the Spanish Ministry of Science, Innovation and Universities Project entitled 'Optimisation of zero-defects production technologies enabling supply chains 4.0 (CADS4.0)' (RTI2018-101344-B-I00)

4 - An interval best-worst multiple reference point method: application in the assessment of non-life insurance companies
Raquel Quiroga, Amelia Bilbao-Terol, Mar Arenas-Parra, Celia Bilbao Terol

In this paper a multi-criteria decision-making (MCDM) method is developed to rank a set of insurance companies. The proposed method is based on to combine two MCDM methods: Interval Best-Worst (IBW) method and Multiple Reference Point (MRP) method. We formulate the problem of finding a priority vector from a set of interval pairwise comparisons by a IBW method which allows the DM to use interval values to describe the relative importance of a criterion over another. The IBW method, using fuzzy set theory, can successfully handle the vagueness and ambiguity in the judgments. Lastly, the MRP is employed to obtain a global score for each company using the weights established in the first stage. A case study is presented to rank Spanish non-life insurance companies based on the constructed model. Since the evaluation of insurance companies involves a great many indicators, it is a complex multi-criteria decision-making (MCDM) issue. The results show the effectiveness of the proposed method and offer an insightful reference for the evaluation of insurance industry.

■ MB-32

Monday, 10:30-12:00 - Virtual Room 32

Decision Support in Investment Management & Banking 2

Stream: Multiple Criteria Decision Analysis
Invited session
Chair: *Michalis Doumpos*

1 - Should Investors Bet on the Jockey or the Horse? Evidence from ECF and VCs funded firms
Karima Bouaiss, Michalis Doumpos, Carine Girard-Guerraud, Constantin Zopounidis

We compare two samples of firms financed by equity crowdfunding and venture capital. The objective is to consider firm-specific criteria and those related to the profile of entrepreneurs to propose a classification based on variables that are usually correlated with each other. Methodologically, we use multicriteria decision analysis (MCDA). Thanks to this integrative methodology, we can determine the key criteria for bankruptcy on a sample of 497 firms, including 277 equity crowdfunded firms and 220 firms financed by VCs. Data on the characteristics of fundraising and on the human capital of the members of the entrepreneurial teams will allow to identify what attracts investors, i.e. "the horse" or "the jockeys". This work will contribute to the literature in entrepreneurial finance by building on the evidence found for venture capital financing, equity-crowdfunding and firm bankruptcy.

2 - Application of MCDM approaches to select consensus algorithms for blockchain systems
Ernestas Filatovas, Marco Marcozzi, Remigijus Paulavičius

Blockchain is one of the most disruptive recent technologies introduced in Bitcoin in 2008. It has already engaged great attention from industry and academia. In the complex architecture of a blockchain system, a consensus algorithm plays a key role. It ensures that all participants (nodes) of a blockchain network agree on the data without any central authority. During the last decade, a wide range of blockchain consensus algorithms have been designed with different concepts and properties (e.g., lower energy consumption, better scalability, smaller latency, higher throughput, better resistance to fault tolerance, etc.). Generally, blockchain systems can be classified based on the participation (private, public, consortium) and permission (permissioned, permissionless) modes. Moreover, each type of blockchains can have additional requirements. Therefore, selecting a preferable consensus algorithm for a particular blockchain system is a challenging task. To facilitate this, the selection of the consensus algorithm could be modeled as an MCDM problem. This work presents an end-to-end MCDM-based approach to identify the preferable consensus algorithm based on the specified criteria and their weights. As each MCDM method has particularities to provide a better analysis level, three popular MCDM methods: SAW, TOPSIS, and ELECTRE III, are employed. We demonstrate the proposed methodology's potential by identifying preferable consensuses for each type of blockchain system.

3 - A Unified View on Diversified Portfolio of Time Series Momentum Strategies Using Multi-Task Learning
Joel Ong, Dorien Herremans

A diversified risk-adjusted time-series momentum (TSMOM) portfolio, is not only able to deliver substantial abnormal returns but also offer some degree of tail risk protection during extreme market events. The success of a TSMOM strategy relies not only on the quality of the momentum signal but also on the efficacy of the volatility estimator. Yet many of the TSMOM strategies which have been extensively studied have always considered them to be independent. Inspired by recent progress in Multi-Task Learning (MTL), we present a new approach, Multi-Task Risk-Adjusted Time Series Momentum (MTL-RATSMOM), that leverages the MTL architecture and consists of two task-specific output layers. The first task-specific output layer is directly trained by optimizing the Sharpe ratio of the signal and the other is trained by minimizing the estimation error between the ex-ante volatility and realized volatility of the assets. During inference, the ex-ante volatility estimates from one task-specific output layer are used to scale the portfolio positions recommended by the other task-specific output layer. Backtesting from January 2000 to April 2020 on a diversified portfolio of continuous futures contracts in bond, commodity, currency, and equity, we demonstrate that even after accounting for transaction costs up to 10 basis points, our approach continues to outperform existing TSMOM strategies. These findings provide important implications for implementation of MTL in finance.

4 - A multicriteria approach for the identification of global systemically important banks
Michalis Doumpos, Silvia Angilella, Sebastiano Mazzù, Constantin Zopounidis

Recent crises have demonstrated that systemic risks constitute a major issue of concern for financial stability. Such risks are particularly important in the banking sector, as the current globalized financial environment has strengthened the interconnectedness of financial institutions around the world. In this context, the identification of global systemically important banks (G-SIBs) is crucial for policy making purposes in the banking sector, as it enables supervisors to spot potential sources of systemic risks at the global level and take actions to mitigate these risks. To this end, the Financial Stability Board (FSB) in consultation with the Basel Committee on Banking Supervision (BIS) has built a methodology to identify G-SIBs. In this research we extend the FSB/BIS methodology through the application of an outranking

MCDA approach. Results are reported for a sample of banks considered in the BIS evaluations over the years 2013-2018. Moreover, a regression analysis is also employed to examine the relationship between the proposed multicriteria evaluation for the global systemic importance of banks and their risk of failure. The results indicate that G-SIBs have higher probability of default.

■ MB-33

Monday, 10:30-12:00 - Virtual Room 33

MCDA Methods 4

Stream: Multiple Criteria Decision Analysis
Invited session
Chair: *Makbule Kandakoglu*

1 - A GIS-assisted Suitability Analysis Framework Using PROMETHEE and k Nearest Neighbor

Kalliopi F. Sotiropoulou, Athanasios P. Vavatsikos

Land use suitability analysis has been applied in several areas of spatial land planning and management like landfill and wastewater treatment units site selection, wind farm siting, site identification for healthcare facilities. Land suitability assessment with respect to a particular use is a spatial complex multicriteria problem since multiple factors need to be taken under consideration such as environmental, design, economic, social for the evaluation of alternative locations concerning planning and environmental restrictions. The integration of Geographic Information Systems (GIS) and Multicriteria Decision Analysis (MCDA) methods is a powerful approach to land use suitability assessment providing suitability index mapping. Outranking multicriteria analysis methods like PROMETHEE and ELECTRE are well suited for land planning purposes. However, their incorporation into GIS-assisted suitability analysis remains scarce when large raster datasets are involved in the analysis due to computational limitations derived from the need to compare in pairs every candidate location. The current study presents a methodological framework that estimates PROMETHEE II net outranking flows and labels to a sample of alternative locations and then applies a classification supervised machine learning approach based on the k Nearest Neighbor algorithm to develop a learning model that can be used to predict classification labels to the examined area generating a suitability map.

2 - An adapted DEMATEL method for fuzzy evaluations

Tjaša Šmidovnik, Petra Grošelj

Decision-making Trial and Evaluation Laboratory (DEMATEL) is a widely used multi-criteria decision-making method to analyze the possible interdependence between elements in a system. Different types of fuzzy sets can be used to incorporate uncertainty into multi-criteria decision making. In our previous research, it was found that the relationships between prominence and relation values are very similar when using different types of fuzzy evaluations (fuzzy numbers, intuitionistic fuzzy numbers and neutrosophic fuzzy numbers). While the use of more sophisticated fuzzy valuations should better explain human reasoning and decision making, it can be more complicated for decision makers to understand. If using more complex fuzzy numbers does not add anything new to the final results, there is no reason to use them. The main cause is early defuzzification of fuzzy numbers in DEMATEL method. The main problem is how to calculate the inverse matrix of fuzzy numbers. The aim of this study is to adapt the DEMATEL method in which the inverse matrix computation is omitted, so that early defuzzification would not be necessary. Our proposed method uses fuzzy evaluations as input, then the adapted DEMATAL method is applied and defuzzification is performed at the end. The method is applied to the case study from literature and the results are compared and analyzed.

3 - A robust multicriteria clustering methodology for portfolio decision analysis

Makbule Kandakoglu, Sarah Ben Amor, Grit Walther

We propose a robust multicriteria clustering methodology for portfolio decision problems in which a subset of projects is selected to form a portfolio by dealing with uncertain multiple criteria evaluations, decision makers' preferences and real-world constraints. Over the last years, many methods have been developed with the aim of maximizing the sum of multicriteria scores of projects selected for the final portfolio. In this paper, unlike the existing literature, we propose a new robust multicriteria clustering methodology that enables to group the best ranked projects with similar preferences into a new kind of cluster (so-called optimal portfolio) that complies with the given constraints. With this aim, a new Integer Programming (IP) model as an extension of the K-medoids clustering technique is combined with the PROMETHEE method. In developing this model, we also introduce portfolio quality constraints to ensure the proper distribution of good evaluations among all considered criteria. We then enhance this combined model by embedding it into the Stochastic Multicriteria Acceptability Analysis (SMAA) framework to consider the inherent uncertainties. As a large number of potentially optimal portfolios are obtained through the SMAA simulation, both project and portfolio level robustness indices are computed in order to help decision makers to identify the most robust and stable portfolio. Our methodology is validated by an example data from a bridge maintenance program.

4 - Cloud Supply Chain System Management due to Global Warming

Faezeh Motevalli-Taher

In today's smart world and the increasing use of cloud space, researchers have paid attention to management and improvement in this field. In line with industry 4 and improving smart cities, how to allocate service providers and applicants for that service is an important and effective factor. By designing an efficient supply chain network, it is possible to help order and optimize this network. In addition, it increases the efficiency and satisfaction of chain members. Environmental issues are also effective factors in decision making in our world. Considering global warming and its factors in decision making is essential. The unstable environment of factors related to global warming leads us to an uncertain context, which made us consider uncertainty in decision making and mathematical modeling.

■ MB-34

Monday, 10:30-12:00 - Virtual Room 34

Scheduling models and algorithms

Stream: Combinatorial Optimization
Invited session
Chair: *Alessandro Agnetis*

1 - Replication and Sequencing of Unreliable Jobs on Parallel Machines

Mario Benini, Alessandro Agnetis, Paolo Detti, Marco Pranzo, Ben Hermans

We consider the problem of sequencing m copies of unreliable jobs (i.e., jobs that have a certain probability of being successfully carried out) on m parallel machines (one copy per machine). A job is carried out if at least one of its copies is successfully completed. If a copy of a job fails, the corresponding machine is blocked and cannot perform the subsequently scheduled job copies. We analyze two problems. In the first problem, each job has a certain revenue which is attained if the job is carried out, and the objective is to maximize the expected revenue. We show that for two machines this problem is NP-hard. We propose a mathematical programming formulation, a metaheuristic approach and an upper bound for the problem. We present a computational campaign on multiple sets of instances with different dimensions and probability intervals for the jobs. The second problem is to maximize the probability that all jobs are carried out. We show that the problem can be easily solved for two machines, as well as for m machines and two jobs.

2 - Batch Scheduling to Minimize Total Completion Time with Uncertain Processing Times
Wei Wu, Takito Hayashi, Haruyasu Kato, Liang Tang

Single-machine batch scheduling can be observed in many real-life applications. One of the significant objectives of this problem is to minimize the total completion time of all jobs, which can be solved in O(n log n) time in the context of deterministic model. However, the deterministic model may lead to unsatisfactory scheduling performance, because uncertain job processing times usually occur due to the facts such as defective products, unexpected machine interruptions, and lack of workforce. To handle such uncertainties, we strive to build a general robust batch scheduling model to minimize total completion time. The uncertainty set of processing times considered in our model encodes a budget of uncertainty (i.e. the number of jobs whose processing times are allowed to vary from their nominal values is limited to a parameter). Two types of batch models, the parallel batch (p-batch) and the serial batch (s-batch), are considered. For the s-batch model, we propose a polynomial-time exact algorithm based on the idea that the robust batch scheduling problem (RBSP) can be reduced to a constrained shortest path problem (CSPP) in a directed acyclic graph. In addition, for the p-batch model, we propose an approach that breaks and transforms the RBSP into two sub-problems, that is, a shortest path problem and a CSPP. The resulting algorithm exactly solves the p-batch model in polynomial time as well.

3 - Flow time minimization in a crossdock truck scheduling problem with asymmetric handover relations
Alessandro Agnetis, Lotte Berghman, Cyril Briand, Quentin Fabry

Crossdocking is a logistics management concept in which various trucks (inbound trucks) arrive to a warehouse (crossdock) carrying items for different destinations. The items are then sorted and loaded on a set of outbound trucks, which will eventually deliver them to the respective destinations, avoiding excessive inventory at the crossdock. During any unloading/loading operation, a truck is docked to a door of the warehouse. We address the problem of assigning the trucks to the doors of the warehouse and sequence them, in order to minimize the total time spent in the system by the pallets. We consider a scenario in which truck processing times are linearly correlated to the amont of pallets being loaded/unloaded (correlated scenario) and a scenario in which they are not (unrelated scenario). We discuss the complexity of the problem, showing that in the unrelated scenario even the single-door problem is NP-hard in general, while the two-door problem is NP-hard even in the correlated case. We also discuss some special cases.

4 - Preemptive Scheduling on Two Unrelated Parallel Machines
Alan Soper, Vitaly Strusevich

In this paper, for the problem of minimizing the makespan on two unrelated parallel machines, we compare the quality of preamptive and non preemptive schedules. It is known that there exists an optimal preamptive schedule with at most two preemptions. We show that the power of preemption, i.e. the ratio computed of the makespan of the best non-preemptive schedule to that of the optimal preemptive schedule is at most 3/2. This result complements the only other known bound on the power of preemption for unrelated parallel machines which is 4, shown to be tight in the limit of an infinite number of machines. We also show that the ratio of the makespan computed for the best schedule with at most one preemption to the makespan of the optimal preemptive schedule is at most 9/8. For both models we present polynomial-time algorithms that find schedules of the required quality. The established bounds match those previously known for the less general problem with two uniform machines. We have found one point of difference between the unrelated and uniform machines: if an optimal preemptive schedule contains exactly one preemption then the ratio of the makespan computed of the best non-preemptive schedule to the makespan of the best preemptive schedule is at most 4/3 if the two machines are uniform and remain 3/2 if they are unrelated.

■ MB-35

Monday, 10:30-12:00 - Virtual Room 35

Vehicle routing I

Stream: Combinatorial Optimization
Invited session
Chair: *M. Grazia Speranza*

1 - The Traveling Salesman Problem with positional consistency constraints
Mafalda Ponte, Luís Gouveia, Ana Paias

In the Consistent Traveling Salesman Problem with positional consistency constraints (CTSP) we seek to generate a set of routes with minimum total cost, in which all the clients are visited in the routes they require service, and clients that need total positional consistency appear in the same relative position in all the routes they are served in. We present several formulations for the CTSP, and study several sets of constraints that can be used to model consistency. We also present a heuristic framework to obtain good feasible solutions for the problem. Finally, both approaches are assessed and compared in a computational experiment.

2 - The Bi-objective Long-haul Transportation Problem on a Road Network
M. Grazia Speranza, Claudia Archetti, Ola Jabali, Andrea Mor

A long-haul truck scheduling problem is studied where a path has to be determined for a vehicle traveling from a specified origin to a specified destination. We consider refueling decisions along the path, while accounting for heterogeneous fuel prices in a road network. The path has to comply with Hours of Service (HOS) regulations. Therefore, a path is defined by the actual road trajectory, as well as the locations where the vehicle stops due to refueling, compliance with HOS regulations, or a combination of the two. This setting is cast in a bi-objective optimization problem, considering the minimization of fuel cost and the minimization of path duration. An algorithm is proposed to solve the problem on a road network. The algorithm builds a set of non-dominated paths with respect to the two objectives. Given the enormous theoretical size of the road network, the algorithm follows an interactive path construction mechanism. It dynamically interacts with a geographic information system to identify the relevant potential paths and stop locations. Computational tests are made on real-sized instances where the distance covered ranges from 500 to 1500 km. The algorithm is compared with solutions obtained from a policy mimicking the current practice of a logistics company. The results show that the non-dominated solutions produced by the algorithm significantly outperform the ones generated by the current practice.

3 - Instance Space Analysis of Capacitated Vehicle Routing Problems
Hamed Soleimani, Kate Smith-Miles, Jussi Rasku, Mario Andres Munoz Acosta

Capacitated Vehicle Routing Problem (CVRP) is a popular optimisation problem in both academia and industry, with a variety of exact and approximation algorithms proposed and developed. These algorithms are usually tested on randomly generated test instances, well-studied benchmark instances, and sets of real-world instances. This paper uses a recently developed methodology known as Instance Space Analysis to explore, for the first time, how the characteristics of CVRP instances affect the performance of algorithms. Using a set of 311 features of instances, we study the performance of nine popular algorithms on a set of 1125 CVRP instances. Using an online instance space analysis tool known as MATILDA, the instance space is visualized using selected features to reveal the diversity of the test instances, and the strengths and weaknesses of different algorithms. Finally, machine learning tools and techniques are used to predict the performance of algorithms to achieve an automated algorithm selection.

4 - The family traveling salesman problem with incompatibility constraints
Raquel Bernardino, Ana Paias

Consider a depot and a partition of the set of nodes into subsets, called families. The objective of the family traveling salesman problem (FTSP) is to find the minimum cost route that starts and ends at the depot and visits a given number of nodes per family. We propose a new variant of the FTSP by introducing incompatibilities between the families, that is, incompatible families cannot be visited in the same route. Thus, the FTSP with incompatibility constraints (FTSP-IC) consists of determining the minimum cost set of routes that begins and ends at the depot; visits a given number of cities in each family; and does not visit incompatible nodes in the same route. We propose compact and non-compact formulations for the FTSP-IC, which model the incompatibility constraints for each family implicitly in the compatibility graph. We also present a new set of valid inequalities. To evaluate the different models, we used the benchmark instances for the FTSP and generated incompatibility matrices. The computational experiment shows that the non-compact models outperform the compact ones. As the exact methods are unable to address the largest sized instances, we developed an iterated local search, which efficiently obtains solutions with a lower value than the branch-and-cut algorithm for most of the instances with an unknown optimal value.

■ MB-36

Monday, 10:30-12:00 - Virtual Room 36

Performance Assessment and Benchmarking

Stream: Multiobjective Combinatorial Optimization
Invited session
Chair: *Andreia Guerreiro*

1 - Techniques to analyze the anytime behavior of algorithms for multi-objective optimization
Alexandre D. Jesus, Luis Paquete, Arnaud Liefooghe, Bilel Derbel

In multi-objective combinatorial optimization it is often not possible to find the efficient set in a reasonable amount of time. As such, anytime algorithms are of particular interest since they allow a decision maker to trade off execution time with solution quality. However, analyzing their anytime behavior, which can be described in terms of a function of solution quality with respect to execution time, is not trivial. In particular, there are two main issues: (i) how to summarize the anytime behavior of an algorithm over multiple runs and/or problem instances; and (ii) how to compare algorithms and make decisions on which algorithm is better, when no algorithm outperforms the others at all times. In this talk we present techniques to build performance profiles that characterize the anytime behavior of an algorithm over different runs or problem instances, and to measure the quality of a performance profile as a scalar value. To demonstrate the practical usefulness of these techniques, we will showcase their application in comparing and automatically selecting algorithms for multi-objective combinatorial optimization problems. Finally, we present a new package for R that implements these techniques and provides a simple interface to use them for the analysis of anytime behavior.

2 - Recent Advances on the Computation of the Hypervolume Subset Selection Problem
Andreia Guerreiro, Vasco Manquinho, José Rui Figueira

Assessing the quality of outcome sets of approximation algorithms for multiobjective optimization is not trivial. Set-quality indicators, which map the image of a set of solutions (a point set) into a scalar value, are a convenient way to do this assessment. These may comprise, in a scalar, the proximity of the set of points to the Pareto front, as well as information regarding the distribution of points in the set. Performance assessment through quality indicators can be viewed as a transformation of the multiobjective optimization problem into a single-objective one, where the goal is to find a point set, frequently of bounded in size, that maximizes the quality indicator. Consequently, each indicator is biased towards some point sets, and some distributions. It is therefore important to understand such biases, in particular, to characterize indicator-optimal subsets.

The hypervolume indicator is one of the most widely used quality indicators due to its desirable theoretical properties. For example, the indicator-optimal subsets are subsets of the Pareto front, and theoretical results on the distribution of points in these subsets are known for the two-objective case. Already for the three-objective case this characterization rely mostly on the empirical approximations of the optimal subsets as the practical use of current algorithms is limited. This work discusses new advances on the computation of the hypervolume subset selection problem for 3 and more objectives.

■ MB-37

Monday, 10:30-12:00 - Virtual Room 37

Graphs, networks and nets in Bioinformatics

Stream: OR in Computational Biology, Bioinformatics and Medicine
Invited session
Chair: *Agnieszka Rybarczyk*

1 - Smart and Interpretable Neural Networks for Classification Learning in Bioinformatics
Thomas Villmann, Marika Kaden

Classification learning currently is dominated by the use of deep neural networks. Yet, these networks usually require a huge amount of data. Further, after training the network decision in the inference phase frequently is difficult to explain. We provide smart and interpretable networks based on prototype learning, which are easy to interpret and, importantly, are proven to be robust. In combination with intelligent data preprocessing the integrating of domain knowledge is possible by appropriate similarity measures like correlations, kernels or information theoretic measures for data discrimination. According to this domain knowledge integration these networks show performances comparable to deep networks while requiring significantly less training data and computational resources. In particular, we present variants of learning vector quantization. Starting from the basic model introduced T. Kohonen, we consider modifications of the basic model such as probabilistic variants as well as adaptive feature waiting, which explicitly offers insights regarding the decision process to the applicants. Further, these models allow an easy to integrate reject option to achieve high classification confidence and model certainty. This option is obtained by the evaluation of the hypothesis margin, implicitly optimized during the classification learning process. We illustrate the approach for application in medical diagnosis support as well as for biomolecular sequence processing.

2 - Structural identification of metabolites from MS/MS spectra by molecular graphs
Piotr Wawrzyniak, Piotr Formanowicz

Disease pathogenesis, drug discovery, response to the treatment - analysis of all of them requires identifying metabolites, small chemical compounds being a product of metabolism. Unfortunately, today only a small fraction of metabolites are known, making identifying unknown metabolites an essential tool for researchers. Mass spectrometry is the most common tool used for metabolite identification. It allows an automated and high throughput analysis of the metabolome, but computer support is necessary to do it accurately and efficiently. Two kinds of algorithms now dominate among the methods of identifying metabolites based on a spectrum of mass spectroscopy, the de-novo methods, basing on fragmentation trees and searching metabolite databases based on decay fragmentation graph. Unfortunately, the first of them recognize unknown compounds, and the second can give information about the structure of the molecule. Finding a way to combine the positives of both methods would be very beneficial. The two above approaches to identifying metabolites can be combined using the generation of the molecular graphs, the labeled multigraphs used to represent the molecules' structure. In the proposed algorithm, the construction of a molecular graph will join described methods. The construction of molecular graphs will make the result of the metabolite fragmentation tree from the de-novo method the input data for the succeeding decay fragmentation tree from the metabolite database search.

3 - Building Hyper-heuristic using crowdsouring
Jan Badura, Artur Laskowski, Szymon Wasik, Maciej Antczak

Hyper-heuristic is a special program that aims to solve optimization problems independently from their search space. Instead, it uses a set of so-called low-level heuristics that are simple algorithms dedicated to solving a specific problem. I would like to use crowdsourcing to collect low-level heuristics. I designed a protocol that enables people to submit their low-level heuristics and implemented it on the Optil.io platform. The system was tested by collecting over a thousand low-level heuristics for a flowshop optimization problem. It is expected that those low-level heuristics form several clusters of similar approaches. I researched several ways of clustering algorithms so that I can choose a set of representative low-level heuristics that hyper-heuristic will use.

4 - The role of cholesterol metabolism in atherosclerosis development and progression - modeled and analyzed using Petri nets
Agnieszka Rybarczyk, Dorota Formanowicz, Marcin Radom, Piotr Formanowicz

Atherosclerosis is a complex process, which is associated with the accumulation of plaque and arterial remodeling. Both lipoprotein retention and inflammatory cellular elements are increasingly recognized as tightly related in the development and progression of this disease. In this study a Petri net based model of the human cholesterol metabolism is presented and analyzed. The model presents some selected aspects of this process and its associations with atherosclerosis progression. In particular, MCT-sets and t-clusters were generated, then knockout and simulation based analysis was conducted. The application of such an approach has enabled for an in-depth analysis of the studied phenomenon and has allowed drawing valuable biological conclusions.

■ MB-38

Monday, 10:30-12:00 - Virtual Room 38

Healthcare Logistics and Services

Stream: ORAHS: OR in Health and Healthcare
Invited session
Chair: *Roberto Aringhieri*

1 - Pharmacy Location Problems: Model Proposition and Analysis
Sophia Wrede, Christina Büsing, Martin Comis, Timo Gersing

Local pharmacies play an important part in the health care system. Their task is to supply the population with medicines and to provide initial assessments on medical issues. In Germany, there are no significant restrictions on the choice of location for new pharmacies to open. However, more pharmacies have been closing than opening for years. This leads to a shortage of pharmacies, especially in rural regions. In this talk, we first discuss conditions that a good pharmacy supply should fulfil. The optimization of pharmacy locations taking these constraints into account and the allocation of customers among open pharmacies leads to a variant of the classical, strongly NP-complete facility location problem. To obtain a more natural allocation of customers, we additionally integrate the theory of bilevel optimization into our model. We call this problem "Pharmacy Location Problem" (PLP). Furthermore, we analyze mathematical structures of the PLP on trees. We can show that even this special case is strongly NP-complete. On paths, however, we present an algorithm with polynomial running time.

2 - New decision support approach for locating self-dialysis centers
Safa Lasmar, Adnen El Amraoui, Hanen Bouchriha, Eric Lefevre, Myraim Gharbi

The research work presented here is carried out as part of a research project from the PHC Utique program (Project N ’ 18G1410). The number of people requiring dialysis is constantly increasing in Europe and Africa which is due to aging populations. To lower hospitals workload and health costs and to improve the patients quality of life, home hemodialysis has emerged as an excellent alternative to traditional hospitalization. In this context, a new aided decision approach is developed to determine the location of dialysis centers (self-dialysis centers), taking into account patient demand variation (death, new patient, grafted, etc.). The developed approach is based on a branch and bound approach. It has been validated on several datasets and the obtained results showed its effectiveness.

3 - Integrated decision making in hospital supply chain management: state-of-the-art and future research opportunities
Lien Vanbrabant, Lotte Verdonck, Silia Mertens

Logistics costs are the second largest cost for hospitals, so effectively managing the hospital supply chain provides significant opportunities for improvement. Hospitals receive and handle a wide range of materials that are directly linked to patient care, such as pharmaceuticals, medical consumables and sterile items. A hospital supply chain is typically designed as a multi-echelon inventory system, consisting of external suppliers, a central warehouse within the hospital, point-of-use locations (i.e. care units) and the patients as final users. In order to optimise supply chain performance and minimise the logistics costs of hospitals, strategic, tactical and operational decisions of the different echelons should be made in an integrated way. These decisions are related to purchasing, production, location, inventory, routing and scheduling. In addition, all real-life features that distinguish the hospital supply chain from other contexts should be included in the decision-making process (e.g. patient safety, perishability, stochasticity). However, research on holistic supply chain management is rather scarce in a hospital context because of the merely supporting role of logistics activities, the high supply chain complexity and the clear boundaries between the different echelons. The aim of this research is to provide an overview of the state-of-the-art regarding integrated decision making in hospital supply chain management and the opportunities for future research.

4 - Novel applications of the team orienteering problem in health care logistics
Roberto Aringhieri, Sara Bigharaz, Davide Duma, Alberto Guastalla

The Team Orienteering Problem (TOP) is a routing problem belonging to the class of the Vehicle Routing Problems with Profits (VRPPs). The VRPP is characterised by the fact that set of customers to serve is not given. This implies the need to consider two different decisions as reported in Archetti et al. (2014), that is (i) which customers to serve, and (ii) how to cluster the customers to be served in different routes (if more than one) and order the visits in each route. The customer selection is driven by a profit associated with each customer that makes such a customer more or less attractive. To the best of our knowledge (Vansteenwegen & Gunawan (2019)), the TOP framework is never applied to the modelling and the solution of health care logistics problems.

In this talk, we present two problems arising in the health care logistics. The former is a problem arising in the digital contact tracing system as a measure for the containment of the Covid-19 pandemic, that is the daily swab test collection (DSTCP) problem. The latter is a problem arising in post-disaster management, that is the Ambulance Routing Problem (ARP) to transport the injured to hospitals. We discuss the formulation of the two problems as TOP and their novelty with respect to the current literature. We also present solution algorithms and their generalization.

■ MB-39

Monday, 10:30-12:00 - Virtual Room 39

Deliveries in urban areas

Stream: Routing, Logistics, Location and Freight Transportation
Invited session
Chair: *Stefan Schaudt*

1 - Crowd shipping using metro stations: a case study evaluation in Brescia

Carlo Filippi

Crowdshipping is a promising shared mobility service that involve the delivery of goods using non-professional shippers. This service is mainly intended to reduce congestion and pollution in city centers but, as some authors observe, in most crowdshipping initiatives the crowd rely on private motorized vehicles and hence the environmental benefits could be small, if not negative. Conversely, a crowdshipping service relying on public transport should maximize the environmental benefits. Motivated by this observation, in this study we assess the potentials of crowdshipping based on metro commuters in the city of Brescia, Italy. Our contribution is twofold. First, we analyze the results of a survey conducted among metro users to assess their willingness to act as crowdshippers. The main result is that most young commuters are willing to be crowdshippers even for a null reward. Second, we assess the potential economic impact of using metro-based crowdshipping coupled with a traditional home delivery service. To this end, we formulate a variant of the VRP model where the customers closest to the metro stations may be served either by a conventional vehicle or by a crowdshipper. The model is implemented using Python with Gurobi solver. A computational study based on the Brescia case is performed to get insights on the economic advantages that a metro-based crowd delivery option may have for a retailing company.

2 - A Load and Time dependent risk metric for the fuel distribution problem in urban areas

Eleni Karouti, Konstantinos Androutsopoulos

Incorporating transportation risk in Hazardous Materials routing decisions constitutes a pro-active safety measure for mitigating the potential consequences of an accident. Our work studies the fuel distribution problem using a heterogeneous fleet of multi compartment tank trucks in order to deliver fuel in urban areas. Two novel features are introduced: i) the balanced loading of the truck compartments adhering to the axles maximum weight limits, and ii) a time and load dependent transportation risk metric. Structural analysis is applied for the calculation of the actual weight bore by each trucks' axle. The risk metric expresses the population exposure as a function of the load carried by the truck, and the duration spent in a given area. The routing process uses a two-phase procedure. A rank-based construction heuristic algorithm is used to create the initial solution. A swap heuristic algorithm is then used in order to provide an improved solution in terms of minimum transportation risk. Finally, a MILP formulation is created for the loading and distribution problem taking into consideration both the load balance constraints and the risk metric.

3 - The Two Echelon Vehicle Routing Problem with Time Windows, Covering Options, and Occasional Drivers

Panca Jodiawan, Vincent F. Yu, Hou Ming-Lu, Aldy Gunawan

This study addresses a new variant of the vehicle routing problem, namely two-echelon vehicle routing problem with time windows, covering options, and occasional drivers (2E-VRPTW-CO-OD). In this problem, two types of fleet are available to serve customers, i.e., city freighters and occasional drivers. Two delivery options can be selected by each customer, i.e., home delivery or alternative delivery. If customers choose the alternative delivery option, the demand of the customers is assigned to one of the available covering options, and customers pick-up the demands themselves. The objective of 2E-VRPTW-CO-OD is to minimize the total cost consisting of routing costs, connection costs, and compensation paid to OD under the condition that all customers are served. We formulate a mixed-integer linear program and propose an adaptive large neighborhood search (ALNS) to provide high-quality solutions to the newly generated 2E-VRPTW-CO-OD instances. The 2E-VRPTW-CO-OD has a special case, the two-echelon vehicle routing problem (2E-VRP). In this special case, our proposed ALNS provides comparable results with the ones obtained by state-of-the-art algorithms. Based on an extensive experiment, decisions in 2E-VRPTW-CO-OD vary depending on the characteristics of occasional drivers and covering options. The results are hence useful for management decision making for the implementation of the system.

4 - A Branch-and-Price Algorithm for a Delivery Network with Autonomous Robots

Stefan Schaudt, Uwe Clausen, Nicklas Klein

The logistics industry has been facing growing transport volumes combined with increasing customer expectations in recent years. To overcome these challenges, new innovative delivery concepts have been developed. One concept for last-mile deliveries in urban environments is based on small electrical robots that drive autonomously on sidewalks and pedestrian zones. These vehicles can deliver goods of daily use such as groceries, parcels, medicine, or meals.

This study examines a delivery network with autonomous robots. The delivery network consists of a fleet of single unit capacity vehicles, a set of depots equipped with recharging stations and a set of customers. Each customer is associated with an individual time window and a profit that can be collected when served. Due to the single unit capacity of the vehicles, a depot visit is required between each pair of customers, which is a difference to classical routing problems. The goal of this problem is to find vehicle routes such that the sum of collected profits is maximized. The problem is solved with an exact branch-and-price algorithm. The pricing problem contains not only the generation of customer sequences, but also the decision on intermediate depot visits and recharging times. Computational studies on benchmark instances show promising results.

■ MB-40

Monday, 10:30-12:00 - Virtual Room 40

Economics and game theory

Stream: Economics and game theory (contributed)
Contributed session
Chair: *Michail Kanakakis*

1 - Strategic partnership formation in networks

Qiongyuan Cao, Joosung Lee

In this paper, we study the role of strategic partnership formation in the decentralized bilateral bargaining game. In particular, our model allows players to strategically choose their bargaining partners and those who reach an agreement will leave the game without replacement. Allowing players to choose their bargaining partner, we find a maximum matching in a Markov perfect equilibrium. It is noticeable that current studies of bilateral bargaining in non-stationary networks focus on pairwise random meetings, which restricts players' bargaining partners. Hence, multiple equilibria may coexist, and the Markov perfect equilibrium fails to yield a maximum matching in some networks. Compared with them, our finding indicates that players will form a link included in a maximum matching no matter what the underlying network is and lead to efficiency.

2 - Evaluating the performance of firms with market equilibria: efficiency and market share

Soobin Choi

In this paper, we study a game-theoretical framework that evaluates the relative performance of firms in a competitive environment with a market equilibrium. Specifically, two normative performance measures in terms of equilibrium prices are considered: efficiency and market share. Defined by the ratio of revenue to cost, efficiency measures a firm's ability to transform inputs into outputs without waste. Meanwhile, market share, defined by the proportion of a firm's revenue to industry's total revenue, assesses the firm's dominance in the market. Since increases and decreases in efficiency and market share reflect the effectiveness of production strategies, the two performance indicators display firms' relative competitiveness. To evaluate these indicators in terms of revenue and cost at an equilibrium, we first characterize the set of equilibrium prices by a Fisher market model with production. In our market model, we describe the production possibilities of firms by using a Data Envelopment Analysis technique, which enables to construct a piecewise-linear estimation of a multi-input, multi-output production set from past input-output production data. With the set of equilibrium prices, we derive formulations that evaluate upper and lower bounds of efficiency and market share. All these formulations, based on convex programming, can be easily implemented by an existing algorithm. We also establish properties regarding our market model and performance measures.

3 - Drivers, Riders and Service Providers: The Impact of the Sharing Economy on Mobility

Michail Kanakakis, Costas Courcoubetis, Saif Benjaafar

It is widely believed that ride sharing has the potential to significantly reduce traffic by filling up cars more efficiently. We introduce a model in which individuals may share rides for a certain fee, paid by the rider(s) to the driver through a ride sharing platform. Collective decision making is modelled as an anonymous non-atomic game with a finite set of strategies and payoff functions among individuals who are heterogeneous in their income. We examine how ride sharing is organized and how traffic and ownership are affected if the platform chooses the fee to maximize either revenue or welfare. We find that the ratio of ownership to usage costs determines how ride sharing is organized. If it is low, ride sharing is offered as a peer-to-peer (P2P) service, and if it is high ride sharing is offered as a business-to-customer (B2C) service. In the P2P case, rides are initiated by drivers only when they need to fulfil their own transportation requirements. In the B2C case, cars are driven by full time drivers taking rides even if these are not motivated by their private needs. We show that the introduction of ride sharing may reduce car ownership, but it can increase traffic. Additionally, that traffic and ownership may increase as the ownership cost increases and that a revenue maximizing platform might prefer cars to be driven with only a few seats occupied, causing high traffic. We contrast these results with those obtained for a social welfare-maximizing platform.

■ MB-41

Monday, 10:30-12:00 - Virtual Room 41

Mathematical Models in Macro- and Microeconomics 2

Stream: Mathematical Models in Macro- and Microeconomics

Invited session

Chair: *Alexander Vasin*

Chair: *Gerhard-Wilhelm Weber*

1 - Hedonic Diversity Games: Nash Stability, the Strict Core, and Social Welfare

Andreas Darmann

A hedonic diversity game (HDG) is a coalition formation problem, where the set of agents is partitioned into two types of agents (say red and blue agents), and each agent has preferences over the relative number (fraction) of agents of her own type in her coalition. In a dichotomous hedonic diversity game (DHDG) each agent partitions the set of possible fractions into a set of approved and a set of disapproved fractions. The solution concepts for these games considered in the literature so far are concerned with stability notions such as core and Nash stability. We add to the existing literature by providing NP-completeness results for the decision problems whether a DHDG admits (i) a Nash stable outcome and (ii) a strictly core stable outcome respectively, in restricted settings with only two (and three, respectively) approved fractions per agent. In addition, applying approval and Borda scores from voting theory we aim at outcomes that maximize social welfare (i.e., the sum of scores) in (dichotomous) hedonic diversity games. In that context we provide an NP-completeness result for HDGs under the use of Borda scores. For DHDGs with approval scores, we draw the sharp separation line between polynomially solvable and NP-complete cases with respect to the number of approved fractions per agent.

2 - Pricing and Technology Competition with Switching Costs

Yang Yang, Cheng-Hung Wu

This research develops a game-theoretical framework between a technology leader and a follower who sequentially developing pricing, technology, and switching cost strategies. Switching cost is the one-time tangible or intangible cost for repurchase consumers when they switch from one provider they have previously purchased to another. As a late-mover advantage, the follower can invest in technology imitation to catch up with the leader while initially being at a technological disadvantage. Meanwhile, both firms can invest in changing product design to alter the switching cost in the market. Under a mixed multinomial logit demand model, theoretical and numerical results are derived by backward induction. We establish the inverse relationship between the technology catch-up investment of the follower and switching costs. Thus, switching costs can be regarded as the first-mover advantage of the leader to impede the technological imitation of the follower. Surprisingly, when the technology gap between the two firms decreases, high switching costs may benefit consumers due to the fierce competition between firms.

3 - The control in hierarchical network systems

Felix Ereshko, Michail Gorelov

Awareness and decentralization are among the main problems in decision-making theory and have attracted the attention of many researches. Particular interest has been shown in these productions recently due to the huge growth in data flow. Experience has shown that, in practice, rather complex organizational systems are managed in a hybrid hierarchical manner and that there are situations where decentralized management is more effective. An explanation of the reason for the effectiveness of decentralization of management was proposed in the works of Germeyer Yu.B. and Moiseev N.N.: if the decision-making person transfers part of decision-making authority to some agents, then joint efforts can make management more effective. Formal mathematical models that can describe this effect are built in the works of Gorelov M.A. and are based on a new representation of game-theoretic constructions using predicate calculus. The paper presents models of different combinations of centralization-decentralization and proposes procedures for calculating the guaranteed results of a dedicated player with different methods of processing data. It is assumed that the object of study has a network character, players in the system are placed in nodes of the graph, and the technological structure of their interactions is set.

4 - Decision-making in the High Frequency Trading Project
Anton Ereshko, *Igor Gasanov*

The report outlines the experience of creating and effectively operating a high-frequency trading robot in the mode of man-machine operations in real trading conditions. The investor made adjustments to the parameters of the robot algorithm. In the intervals between these actions, trading is carried out automatically in milliseconds according to the rules set by the investor. To adjust these rules, a computing complex was developed that includes a detailed simulation model of bidding. A quantitative criterion is formed on the basis of dynamic indicators based on market data received. Exceeding this threshold is a signal to a financial instrument purchase or sale transaction. The function for calculating the criterion contains numerical parameters. These parameters, like the threshold value, are configurable and depend on the current state of the market. Special methods have also been developed to adjust the parameters of the robot on the historical rows of trading observations. Using all available data did not make sense, since the market is constantly changing and the value of the old experience is falling. At the same time, the use of short series of observations can lead to adapting parameters to the specifics of a small sample that does not reflect general trends and is not valuable for the upcoming bidding period. The robot has shown its effectiveness in real trade and in training competitions of private investors held by the exchange.

■ MB-42

Monday, 10:30-12:00 - Virtual Room 42

Purchasing and supplier selection in sustainable supply chains

Stream: Sustainable Supply Chains
Invited session
Chair: *Gizem Mullaoglu*

1 - Coordinating contracts for a reverse supply chain with a segmented customer base
Grigory Pishchulov, *Janu Rajendran*, *Anastasia Nitchenkova*

The circular economy paradigm refers to collection, recovery and reuse of used products, which helps to lessen the environmental impact of the world economy by reducing landfill and consumption of raw materials, while offering economic benefits due to residual value of used products. The return flow of used products gives rise to reverse and closed-loop supply chains, which require coordination among supply chain members. The work by Zeng (2013) [Coordination mechanisms for a three-stage reverse supply chain to increase profitable returns, Nav. Res. Logist. 60, 31-45] studies coordination in a reverse supply chain involving a manufacturer and a retailer who coordinate their actions via a revenue-sharing contract. Differently from much of related work, Zeng proposes an empirically validated model of customer base segmentation, in which different customer segments have different motivation and different incentives for returning used products. In the present work, we pursue further analysis of Zeng's coordination problem and demonstrate that the revenue-sharing contract type adopted in the original study setting does not generally entail supply-chain coordination. We further demonstrate that coordination deficit can be significant. To address this issue, we propose three different types of contracts that help supply chain members achieve supply-chain coordination. We further demonstrate the extent of economic and environmental benefits of coordination on a number of examples.

2 - Assessing the Supplier Selection Criteria based on Minimizing Pre-consumer Fabric Waste
Navodi Wijayarathne, *Shirekha Layangani*

Incorporating waste minimization techniques for the apparel industry is becoming a key priority. Thus, prevention of waste at early design stages are being considered in the modern context. The study explores the possibilities to reducing Pre-consumer apparel waste by assessing the influence of supplier selection criteria to prevent pre-consumer fabric cutting waste at the early design stages. If the optimum fabric type can be chosen when sourcing the fabric, it can lead to a reduction of fabric cutting waste. Therefore, supplier selection criteria should be thoroughly overlooked. The study analyzes the frequently used supplier selection criteria when sourcing fabric in Sri Lankan Mass Apparel Manufacturing sector. Additionally, it aims to introduce a new supplier selection criterion that would lead to fabric cutting minimization. The study consists of a case study scenario to validate the findings using a Multi-Criteria Decision-Making model (MCDM). The intuitionistic Fuzzy TOPSIS method is used as the MCDM model to validate the linguistic human judgments involved in the supplier selection process. As a result, Fabric width is finalized as the new supplier selection criterion in terms of sourcing fabric in the mass apparel manufacturing industry in Sri Lanka. The possible reduction of fabric cutting waste due to the new criterion is assessed using the maker-efficiency ratio. The study concludes opening new avenues for supplier negotiations in future research directions.

3 - Food Supply Chain Management by a Sustainable Approach to Supplier Evaluation
Marina Segura, *Concepción Maroto*, *Baldomero Segura*, *José Carlos Casas-Rosal*

The evolution of supply chain management over the last decades has shown a remarkable change in company purchasing departments towards the strategic role of their activities, such as the evaluation of providers and the decision-making in this area. The objectives of this research are to develop models to solve real-world supplier evaluation problems and validate them with real data on fresh fruits in a supermarket chain. Literature review and results from a survey with managers from purchasing, logistics, and quality departments of a food distribution company are used to establish criteria, to first model the assessment of products and, second, to model supplier evaluation. A multicriteria hybrid approach is proposed, using multi-attribute utility theory (MAUT) to assess the quality of products and Preference Ranking Organisation Method for Enrichment Evaluation (PROMETHEE) to complete their evaluation with strategic criteria to be included in the second phase. The results allow companies to rank suppliers by product and classify them according to the main criteria categories, such as product strategy, food safety, economic, logistic, commercial, green image and corporate social responsibility. A sorting approach is also applied to obtain ordered groups of suppliers. Finally, the models proposed can form the core of a decision support system in order to create and monitor the supplier base in food distribution companies, as well as to inform sustainable decision making.

4 - The analysis of the performance-based contracts from the perspective of circular economy
Gizem Mullaoglu, *Tarkan Tan*

The United Nations proposed 17 sustainable development goals, to be achieved by 2030, including issues related to health, responsible consumption, and production amongst others. One of the best ways to achieve the latter goal is through the Circular Economy (CE) without jeopardizing growth and prosperity. The CE offers significant economic benefits in addition to its environmentally-conscious perspective as a result of the improved resource productivity. Therefore, to achieve sustainable development, establishing a high degree of collaboration in CE is inevitable. Without collaboration, stakeholders' actions in the supply chain are not always in the search of the overall best performance of the supply chain but the primary aim is to optimize individual objectives, and these individual concerns often yield poor overall performance. However, optimal overall performance is achievable if the firms coordinate by contracts such that each firm's objective becomes aligned with the supply chain's objective. Our study focuses on the coordination between a supplier and a manufacturer in which contracts are designed to incentivize circularity. We analyze and compare the performance-based contracts on the circularity via a multi-objective model. We aim to shed light on the contract design issues from the CE perspective and provide beneficial insights and fruitful results for the opportunities in contract design via circular economy.

■ MB-43

Monday, 10:30-12:00 - Virtual Room 43

Stochastic models in inventory, emergency departments and blood donation

Stream: Stochastic Modeling in Health Care
Invited session
Chair: *Martina Doneda*

1 - A discrete-event simulation model for analyzing and improving operations in a blood collection center
Martina Doneda, Semih Yalçındağ, Inês Marques, Ettore Lanzarone

Many literature reviews highlighted that the attention dedicated to the donation step of the blood supply chain is marginal, in comparison to other stages (e.g. storage). Motivated by this, we built a Discrete-Event Simulation (DES) model to study the daily operations in a blood collection center (BCC). We also included a feedback loop from the DES to the appointment scheduling level. The DES model was built in a parametric form, to allow maximal flexibility and customization. We had a twofold aim: i) analyzing and comparing different center configurations; ii) evaluating the effectiveness and feasibility of donor schedules defined beforehand thanks to the loop, which allowed to adjust planning decisions if they determined operational criticalities or infeasibilities. We tested the DES considering the data of a real Italian provider. We designed an experimental plan to compare different scenarios for the chosen BCC. We selected the best ones using the perspectives of the three main stakeholders involved (donors, BCC personnel and BCC managers). These configurations were used to test the feedback loop. Results confirmed the appropriateness of the proposed DES model. It can be used as a decision support tool for dimensioning and managing a BCC, either as a standalone tool or in conjunction with a higher-level scheduler, exploiting the feedback loop. Thanks to its parametric form and inherent flexibility, it is capable of being deployed in a variety of use-cases.

2 - An Integrated Framework for At-Home Blood Collection
Semih Yalçındağ, Martina Doneda, Ettore Lanzarone, Inês Marques

Blood Donation Supply Chains (BDSCs) are one of the most critical components of health care systems. According to a recent study, the 2017 global need for blood was estimated to be 300 million units, whereas the collection rate was only around 270 millions. Providing a sufficient supply of blood has always been a global challenge, as blood can only be produced from human donors. The COVID-19 pandemic has worsened this issue, and shortages have dramatically increased. According to the Italian National Blood Center, the production of red blood cells in April 2020 was reduced by 36.4%, compared to the one of April 2019. To increase donations and decrease shortages, in this work we are considering an integrated framework to collect blood at the donors' homes, rather than in donation centers. To successfully achieve this, we linked the Blood Donation Appointment Scheduling (BDAS) and the Multi-Trip Vehicle Routing Problem with Time Windows (MTVRP-TW) problems. This framework consists of three planning phases. First, possible time slots for donor appointments are created, with the aim of balancing the production of the different blood types. These slots are then turned into real appointments, according to the received booking requests. Finally, a fleet of vehicles is organized to collect blood from the donors' homes, at the predefined donation day and time. The proposed framework has been tested and validated with the data obtained from an Italian blood collection center.

3 - Managing Healthcare Inventory under Extreme Uncertainty using Hidden Markov Models
Shirekha Layangani, Fernando Oliveira, Valery Pavlov

Demand for medical and surgical items in hospitals is highly volatile, noisy, and non-stationary. Due to these complexities and uncertainties, forecasting has become a challenge in healthcare. In addition, hospitals face difficulties due to frequent errors in demand records. These errors directly impact on the cost and quality of healthcare service because wrong records can cause stock-outs of critical items, while excess can cause wastage and increased costs. Hence, detecting abnormal demand patterns in demand records is useful for decision makers. We introduce a framework to model extreme demand patterns and inventory management in healthcare, based on Hidden Markov Models. We are able to better explain the conditions under which extreme demand and possible stock-outs are likely to occur, and to increase the efficiency and effectiveness of the inventory management system, which is able to maintain a higher quality of service at a significant lower cost. We apply the framework to products with different volumes and costs and test it using a Markov Decision Process, estimating the improvements in terms of costs and stock-outs achieved by the proposed Hidden Markov Model.

4 - Simulation of Hospital Processes During Covid-19 Pandemic
Veysi Isler, Umut KiliÇ, Merve Durmaz

Ever since the Covid-19 virus is considered a pandemic, there has been concern about whether medical resources and supplies, including hospital beds, intensive care units, ventilators, and protective equipment, will be adequate in healthcare facilities. Forecasting intense demand plays an important role in informing healthcare professionals and governments about how to manage healthcare systems. In this direction, we have developed a discrete event simulation. Simulation allows many 'what if?' scenarios to be tested. This allows decision-makers to test and better understand alternative ways in which a new policy may be best met. Taking advantage of the Covid-19 open-source studies, the data obtained were defined as inputs to the simulation model. With these inputs, the density and bottlenecks that may occur in the hospital were examined by running our model for 5 days. Based on all these, the three most important factors were used in the model. These include the number and supply of materials required for healthcare professionals and the number of beds required for patients. Thanks to this simulation, it tells how many beds are required in intensive care, services and gloves should be supplied for the hospital, or how many Covid-19 tests will be performed per day.

■ MB-44

Monday, 10:30-12:00 - Virtual Room 44

How OR became my business: OR users speak out

Stream: Practice of OR (Making an Impact)
Invited session
Chair: *Michele Quattrone*
Chair: *Ruth Kaufman*

1 - How OR became my business....
Michele Quattrone

We are used to thinking about how we can market OR, and how we might get a potential customer interested in what we have to offer; sometimes successfully, sometimes not so successfully. This session gives us a chance to explore the problem from the clients viewpoint. A panel of customers of OR will be invited to talk about how they discovered OR, and how they integrate it into their project. This will then be opened up to Q&A, to find out more about what makes a good OR project, and a good OR practitioner, from the customer's viewpoint.

Speakers include: Cedric Valente, with 15 years of experience of leading transport management systems projects; Antonio di Carmine and Massimo Rosti of Alstom, Lead Architect and Solutions Director of Alstom's Traffic Management System; and Ed Humpherson, Director General for Regulation at the UK Statistics Authority. For the latest details of speakers and their positions on OR, visit the 'Making an Impact' webpages here: https://euro2021athens.com/specific-sessions/

■ MB-45

Monday, 10:30-12:00 - Virtual Room 45

Newsvendor problems and supply management

Stream: Production, Service and Supply Chain Management
Invited session
Chair: *Yasemin Merzifonluoglu*

1 - The price-setting newsvendor problem with barter exchange in adverse market circumstances
Milena Bieniek

We study the price-setting newsvendor problem with barter exchange. The barter price is assumed to be endogenous and equal to the retail price. We consider the customer stochastic demand which is additive and linearly dependent on the price. The additive uncertainty may allow negative demand realizations, especially in adverse market conditions and therefore we take into account this fact in our model. We prove that the solution to the newsvendor problem with barter exchange may be suboptimal and incomplete without the nonnegativity constraint.

2 - An integrated dynamic lot sizing and supplier selection problem with payment modalities
Oussama Kajjoune, Tarik Aouam, Tarik Zouadi

The integrated dynamic lot sizing and supplier selection problem has typically been studied in the context of optimizing the physical flow of goods, assuming there is always enough cash to finance operations. In reality, however, companies need to also manage cash flows and ensure that production and procurement plans are financially viable. The present study jointly optimizes dynamic lot sizing, supplier selection and cash flows, considering working capital requirements to finance production and procurement activities. We consider a manufacturer that produces single item and procures raw-materials from a set of suppliers, each with specific costs and payment modalities. The manufacturer must decide on the quantities to produce and the quantities to order from suppliers in each period, while satisfying operational and financial constraints, with the objective of maximizing the net present value of cash flows. The integrated problem is formulated as a mixed integer nonlinear program (MINLP) and solved using a local-search metaheuristic. Through numerical experiments, we analyse the basic trade-offs between cost and payment delays, and study the effect of various parameters on these trade-offs. Extensive computational experiments are conducted to evaluate the performance of the proposed solution procedure.

3 - Hub Interdiction Problem Under Congestion: Models and Solution Methods
Sneha Bhatt, Ankur Sinha, Sachin Jayaswal

In this paper, we look at the interdiction problem under the case of congestion. In case of any disruption, intentional or random, that causes complete failure of some of the hubs, re-routing all the flows through the remaining hub facilities by just considering costs based on distances may result in a network that may assign most of the flows to the nearest hubs. However, this may make some hubs highly congested and may aggravate the effect of the disruption. In case of an interdiction (intentional attack), we study the case where the defender would consider re-routing all the flows while also avoiding congestion at the hubs. The following two ways are considered to model congestion: i) We assume hubs as spatially distributed M/G/1 queues that account for any uncertainty in the arrival and service rates. ii) We model congestion function as a power-law function that is convex and increasing in the total flows at the hubs. Incorporating one of the above functions in the interdiction framework leads to a max-min problem with a non-linear lower-level objective function. We use two exact approaches to solve the problem to global optimality and present their computational performance. The first approach is based on using linear-approximations that overestimates the non-linear objective function of the defender's problem. In the second approach, we use a second-order conic programming based reformulation of the lower level problem, which can be solved using an off-the-shelf solver.

4 - Procurement Portfolio Planning for a Newsvendor with Supplier Delivery Uncertainty
Yasemin Merzifonluoglu, Roshanak Mohammadivojdan, Joseph Geunes

We consider the problem of allocating procurement quantities for a required input to multiple suppliers in advance of a selling season with uncertain demand. Planning complexity is compounded by uncertainty in whether each supplier will deliver on time, in addition to the existence of an option for reserving capacity with a perfectly reliable supplier and the presence of a spot market for the input with an uncertain price. We apply analytical methods including two-stage stochastic programming with recourse, nonlinear optimization, and exact and efficient model-based heuristic solution methods. We show that for a selected supplier, the newsvendor's conditional service level, given that the supplier delivers on time, equals a critical ratio value determined by the supplier's cost and reliability parameters. Post-optimality analysis reveals interesting insights on the way reliability and cost parameters interact to determine whether a supplier receives a positive order allocation, as well as the impact of payment schemes on supplier selection decisions. The analysis clarifies an insightful relationship between the conditional service level and a critical ratio value for each selected supplier. The results also sharpen insights on the way relative supplier reliability and cost parameter values interact to determine an optimal supply portfolio.

■ MB-46

Monday, 10:30-12:00 - Virtual Room 46

Stochastic Models II

Stream: Stochastic Models in Manufacturing and Services
Invited session
Chair: *Pepa Ramirez Cobo*

1 - A stochastic dynamic model estimating reputation with wear in-wear out levels and sales based on digital advertisement
Hakan Ak, Burak Pac

Reputation built through digital marketing plays a key role on sales, and digital marketing sales have grown by leaps and bounds, becoming the biggest marketing mean. In this paper, we firstly model the reputation concept by a "wear in" function of marketing expenditure over periods through different channels of digital marketing, and a "wear out" rate over each period. Sales depends on the reputation level in a period, along with direct click-through effects of advertisement channels, and is estimated by multiple linear regression. We use the Gaussian error model in line with linear regression to generate scenarios for the consumer response to expenditure decisions. Total profit maximizing scenario based stochastic dynamic model is shown to reduce marketing expenditures while achieving the objective. The result is computationally confirmed on the test data, comparing to decisions of the marketing department experts.

2 - New insights on the MAP counting process
Pepa Ramirez Cobo, Rosa Elvira Lillo Rodríguez, Marcos Gonzalez Bernal

Markovian arrival process (MAPs) are known to constitute a versatile class of point processes that allow for dependent inter-arrival times. In this work, we aim to exploit such property for modeling modern call centers, which are characterized by non-negligible dependence patterns. Most of previous statistical approaches for MAPs are based on the distribution of the inter-arrival times. In this work, however, a different perspective is adopted, being the inference focused on the properties of the associated counting process. In particular, this work deepens into the counting process' covariance function for which almost the only thing that is known is its closed-form expression. New properties concerning the correlation patterns and monotonicity shall be illustrated.

3 - Alternating alpha-series process: Properties and Applications
Sarah Marshall, Richard Arnold, Stefanka Chukova, Yu Hayakawa

The lifetime of a repairable system can be modelled as an alternating sequence of operational times and repair times. In the case of ageing systems, operational times tend to decrease and repair times tend to increase. In this presentation, we introduce the alternating alpha-series process, which can be used to model this type of ageing system. This study on the alternating alpha-series process extends previous work on the alternating renewal process and the alternating geometric process. We present some properties of the alpha-series process and introduce two counting processes, associated with it. Also, we discuss an application of these two counting processes to warranty cost analysis.

4 - Linear programming decomposition for dynamic dispatching and preventive maintenance of unrelated parallel machines
Bin Zhang, Cheng-Hung Wu

A linear programming decomposition (LPD) method is developed to reduce the computational complexity of solving dynamic dispatching and preventive maintenance (DDPM) problems. Although the DDPM problems can be modelled and solved by Markov decision processes, the required computation time increases exponentially with the number of unrelated parallel machines. Consequently, solving DDPM problems is computationally infeasible in large manufacturing systems. In order to reduce computational complexity, the LPD method is introduced to decompose large DDPM problems into single-machine DDPM problems. The objective function of the LPD method is to maximize the overall capacity redundancy of machines. Through the optimal capacity allocation of unrelated parallel machines, the computational complexity of solving large DPPM problems grows linearly with the number of unrelated parallel machines. Furthermore, simulation results show that the LPD approach generates near optimal solution for DPPM problems and the performance of the LPD approach is superior to other dynamic dispatching methods from the literature.

■ MB-47

Monday, 10:30-12:00 - Virtual Room 47

Emerging Applications in Management Science III

Stream: Emerging Applications in Portfolio Selection and Management Science
Invited session
Chair: *Michael Zhang*

1 - A machine learning approach to speed up resource constraint evaluation for the crew rostering problem.
Michael Zhang, Andrea Raith, Andrew J Mason, Oliver Weide, Olga Perederieieva

When airlines solve a crew rostering problem, the solutions obtained must respect the airline industry's many rules and regulations. We use a column generation based solution method with resource constrained shortest path problems (RCSPP) as subproblems to solve the crew rostering problem. Typically, the rules are modelled as constraints and resources in the RCSPP. The number and specifics of the rules may vary over time and between airlines, and they can be a burden to re-implement in RCSPP every time a change is necessary. We work with a commercial partner who uses a complex and highly configurable external rule evaluator to calculate resource constraints. The rule evaluator provides a level of abstraction between the RCSPP implementation and the resource constraints to handle the various airline requirements. Calling this rule evaluator can be computationally expensive when paired with the NP-Hard nature of solving RCSPP problems. We obtain and use the large amounts of data found during the solution process and apply machine learning (ML) techniques to explore heuristic ways to decrease the computational cost of calling the rule evaluator. We investigate how well our ML models can identify and discard infeasible partial RCSPP solutions instead of calling the rule evaluator. The intention is to integrate our approach into the overall solution process and evaluate the effects of our predictive models' inclusion when applied to real-world problem instances.

2 - The Aircraft Landing Problem with Target Landing time Windows
Allen Zhou, Feng-Jang Hwang, Yao-Huei Huang

The aircraft landing problem (ALP) involves sequencing the aircraft landings and assigning the corresponding landing times for an airport, considering the minimisation of costs incurred by the early and late arrivals. In the existing studies, each aircraft landing is associated with a target landing time, any deviation from which will incur a penalty cost of earliness or lateness. Besides, a hard constraint regulating a minimum separation time between consecutive aircraft landings is imposed for safety requirements, and the separation time depends on the types and sizes of the landing aircraft. Each aircraft landing is required to be within the time interval between its predefined earliest and latest landing times. In this study, we investigate a generalised case in which the target landing time is expanded to a target landing time window. In the ALP with target landing time windows (ALP-TLTW), an aircraft that lands within the bounds of the target time window incurs no cost. An ILS (iterative local search)-type heuristic algorithm is developed to solve the ALP-TLTW for the minimisation of total weighted earliness and lateness. Our preliminary experimental results indicate the effectiveness and efficiency of the proposed solution method. The comprehensive computational results will be reported and discussed.

3 - Crew Teaming in Airline Pairing Optimization.
Waldemar Kocjan

Airline crew planning is a process performed in several consecutive stages. It starts with manpower planning, estimating the crew necessary to perform planned airline operations. In the next crew pairing phase, a set of anonymous trips are created, series of flights starting and ending at a specific crew base, which take into consideration crew needed to perform each flight. Finally, in the rostering stage, created trips are assigned to the real crew.

Creating trips in the pairing phase is subject to different requirements. Crew teaming is a requirement to keep a flight crew together between certain flights, during a working day or even throughout a whole trip. Fulfilling such requirement is of great importance from the point of view of operational stability of a crew schedule, however it is very difficult due to differences in rules and costs between different crew positions. The trade-off between cost of the solution and degree of teaming is a significant challenge.

In this presentation we will address how teaming is encourage inside the Jeppesen Crew Pairing product.

■ MB-48

Monday, 10:30-12:00 - Virtual Room 48

Zilla Sinuany-Stern

Stream: Keynotes
Keynote session
Chair: *Pascale Zaraté*

1 - Foundations of OR: from LP to DEA
Zilla Sinuany-Stern

Operations Research (OR) as a discipline was born during WWII in UK and USA, when scientists from various disciplines gathered to solve complex military operations, such as: resource allocation, location and logistics. Thereafter, OR was successfully applied to civil problems. OR is a combination of several disciplines: Mathematics, Computer Science, Statistics, Economics, Business and Industrial Engineering - and has many titles, such as: Management Science, Decision Science and Analytics. Although, initially, OR was interdisciplinary, it developed in the direction of mathematical modeling of complex systems, and problems, which often do not have a closed-form mathematical solution. Linear Programming (LP), with its Simplex algorithm, developed by Dantzig in 1947, is the preeminent methodology associated with OR. LP stems from the simplest economic production problem (i.e., how much should be produced of each product to maximize profit or minimize cost under resources constraints) - in which objective function and constraints are linear and the variables are non-negative. The success of Simplex, and other OR algorithms is due to the rapid, development of Computer Science, another innovative, post WWII science. Ever since, LP has developed in multiple directions, such as: large scale optimization, approximations for non-LP problems, Integer Programming (IP), mixed IP, transportation, timetabling, networks and Data Envelopment Analysis (DEA). Some of these developments required new, improved, and faster algorithms. DEA (1978) deals with another economic problem - finding the efficient frontier of decision-making units (DMUs) - based on given inputs and output data ex-ante. DEA employs sets of LP problems - one for each DMU - to determine the efficiency of DMU. The lecture covers the history of OR, LP and its derivatives - focusing on developments in DEA.

■ MB-49

Monday, 10:30-12:00 - Virtual Room 49

AI4RAILS keynote

Stream: The 2nd International Workshop on Artificial Intelligence for RAILwayS (AI4RAILS)
Invited session
Chair: *Nikola Besinovic*

1 - Keynote: Data Science in Alstom: Our Road from Mobility Leader to Digital Giant
Nenad Mijatovic

In this talk, Dr. Nenad MIJATOVIC is going to provide real-life experience on how data science has been used to accelerate digitalization in Alstom. Nenad will share Alstom's insights on building successful data science teams, delivering proper ML and AI software modules, and dealing with data challenges in mobility. Also, he will provide some specific examples of ML and AI algorithms used to solve complex problems from data.

■ MB-50

Monday, 10:30-12:00 - Virtual Room 50

Emerging Collaborative Economics and Management under Uncertainty 3

Stream: Emerging Collaborative Economics and Management under Uncertainty
Invited session
Chair: *Gerhard-Wilhelm Weber*
Chair: *Sırma Zeynep Alparslan Gök*

1 - VND-based algorithm on Packing and scheduling for lockage through Three Gorges and Gezhouba Dams
Xiaopan Zhang, Julia Bennell

The Three Gorges Project in the upper middle Yangtze River is composed of the Three Gorges Dam and the Gezhouba (abbr. GZB) Dam. Besides the significant power generating capability, the project has increased the shipping capacity remarkably. Two locks and a ship lift in the TG dam and three locks in the GZB dam offer six canals for vessels to traverse the dams, which face heavy cargo traffic every day. As the two dams locate closely and have been managed centrally, it is necessary to co-ordinate the lockage scheduling for both dams to improve transport quality and save lockage resources including water and energy within a given scheduling period. The problem was modelled as a deterministic bi-objective sequential 2D Next-Fit bin-packing where the small items are vessels and the bins are the locks. A parameterized VND algorithm with four neighborhood structures was proposed to practice different local search ranges and a new lockage usage evaluation function was designed to intensify sensitivity of lockage usage objective. A rolling horizon version VND algorithm was generated to deal with longer period or larger scale traffic. Experiments were carried out based on four kinds of traffic flows with different area and shape distributions of vessels simulated according to the real historical lockage request data. The results showed remarkable optimization of each individual objective from the initial FCFS solutions.

2 - Large Scale Pricing Optimization for online fashion platform
Vladimir Fux, Andrea Taverna, Torsten Gellert, Thorsten Greiner, Gaurav Bhardwaj, Mariyam Fedoseeva, Nikhil Sethi, Rodrigo Witzel, Sebastian Engels, Sebastian Wozny, Hanwei Li, Xiao Wu, Rui Sun, David Simchi-Levi

In this work we discuss pricing recommendations problems tackled at Zalando, Europe's leading online fashion platform. The weekly pricing recommendations need to provide discounts for several hundred thousands Stock Keeping Units (SKUs) for all markets. Additionally, for each SKU a number of business constraints should be considered. Such recommendations span multiple weeks aiming to provide accurate information for logistical and commercial planning. This problem can be solved efficiently for each SKU independently and is similar to the classical newsvendor problem. However, the decision process includes additional business requirements, expressed as targets for commercial KPIs, which provide users fine control on pricing at markets and business units levels. These targets are formulated as "global constraints" that bundle together multiple SKUs and make thus the problem much harder to solve. We tackle this challenge with a Lagrangian decomposition approach, which decouples the problem again into multiple independent subproblems. The dual variables are optimized via the Cutting Plane algorithm and a final primal solution is computed via combinatorial heuristics that exploit the primal solutions generated during the dual optimization. To match the scale of our assortment, we implement massive parallelization using an advanced big-data pipeline on Spark which optimizes the Lagrangian subproblems efficiently with an open source solver

3 - Preference Disaggregation Approach of CODAS method
Mouna Regaieg

The Multi-Criteria Decision Making (MCDM) tackles four types of problems: ranking, sorting, choice and description. The aggregation method CODAS (COmbinative Distance-based Assessment) is a new MCDM method that consists in ranking each alternative from the best to the worst. However, it requires fixing parameter values directly by the decision maker (DM) in a subjective manner. The objective of this paper is to develop a preference disaggregation approach in order to determine objectively the CODAS threshold value from binary preference relations provided by the Decision Maker. The proposed approach is based on mathematical programming. Like any preference disaggregation method, the problem consists in minimizing the inconsistency between the model obtained with this parameter and DM's preferences. Furthermore, an illustrative example is performed to check the performance of this disaggregation approach. Finally, sensitivity analyses are carried to check the sensitivity of the results while varying thresholds.

4 - Finding the adequate solution for a real waste collection problem using an interactive method
Laura Delgado Antequera, Francisco Ruiz, German Gemar, Rafael Caballero

In the last few years, public organizations show an increasing willingness to solve real problems with multiple criteria. In particular, waste management involves a set of economic, social, labor and environmental aspects, which implies a big effort from these companies that must provide a good service. Many algorithms have been developed in order to obtain the best set of Pareto solutions for this kind of multicriteria real problems, according to their different particularities. However, despite the large number of proposals dealing with multicriteria waste collection problems, just a few papers present a friendly discussion method, from which the decision maker (DM) is able to learn from the process, analyze the situation and reset the parameters to explore, from the given set of feasible solutions, in order to find the best, according to his preferences. To facilitate the information exchange between the analyst and the decision maker along the decision making process, we present an interactive method implemented within a graphical user interface (GUI). In this context, a valid approach to the Pareto Set is externally generated. To conclude, we apply this methodology to provide the right solution for a regional waste collection problem from the south of Spain.

■ MB-51

Monday, 10:30-12:00 - Virtual Room 51

The Value of Information in Optimal Control

Stream: Optimal Control Theory and Applications
Invited session
Chair: *Thorsten Upmann*

1 - Instantaneous Control of an Inventory with Unknown Trend
Giorgio Ferrari, Salvatore Federico, Neofytos Rodosthenous

In this paper, we study the problem of optimally managing an inventory with unknown trend. Our formulation leads to a stochastic control problem under partial observation, in which a Brownian motion with not observable drift can be singularly controlled in both an upward and downward direction. Assuming that the demand's trend is a Bernoulli random variable, we first derive the equivalent separated problem under full information and we then completely solve the latter. In particular, we show substantial regularity of its value function, we construct an optimal control rule, and we show that the free boundaries delineating action and inaction regions are Lipschitz continuous. Our approach uses the transition amongst three different but equivalent problem formulations and a link between two-dimensional bounded-variation stochastic control problems and games of optimal stopping. In order to show that the value function of the control problem possesses the sufficient regularity needed to perform a verification theorem, we develop a probabilistic method in combination with refined viscosity theory arguments.

2 - Expanding Multi-Market Monopoly and Nonconcavity in the Value of Information
Stefan Behringer

I investigate a Bayesian inverse problem in the specific setting of a game with a price setting monopolist facing a randomly growing demand in multiple interconnected markets. Investigating the Value of Information of a signal to the monopolist, both in full and pro-rata, we find that the former can be non-monotonic in the variance of the signal whereas the latter will always be monotonic. This implies that there are ranges of the signal noise over which the Value of Information may either decline or increase. This range critically depend on the exogenous growth rate of the market potentials.

3 - Optimal environmental policy adoption under unpredictable future social costs
Neofytos Rodosthenous, Giorgio Ferrari

We study the problem of optimally adopting an environmental policy to reduce emissions, when the socioeconomic impact of pollution is unpredictable (e.g. related to uncertain future technological advances). In this talk, we formulate this task as an optimal timing problem under partial observation of the (random) drift of the stochastic social costs of environmental pollution. Using the filtering estimate of the unknown drift, the social planner continuously learns (updates her belief of) the true average social cost and the problem thus becomes two-dimensional. We develop a probabilistic methodology building on three different but equivalent formulations of the problem to construct an optimal policy which minimises the overall costs of atmospheric pollution stock and its derived (partially-observable) social costs counterbalanced by the sunk costs of policy adoption. The strategy prescribes adopting the policy when costs breech a threshold which is a function of the social planner's learning process.

4 - The impact of the information about the initial conditions on the solution of cooperative differential games
Ekaterina Gromova, Anna Tur

We consider a class of continuous time optimal control problems in which there are n decision-makers (players) that have an opportunity to cooperate, namely, a class of cooperative differential games.

For this class of games, we study how the knowledge about the initial state changes the solution both in the sense of players' payoffs and the respective cooperative solutions such as the Shapley value, the Banzhaf index, and the core.

To illustrate our analysis of the value of information we consider an example from the differential game of non-renewable resource extraction. Furthermore, we demonstrate how the information about the time horizon of the game changes the cooperative solution.

The work of E. Gromova is supported by the Russian Science Foundation (project no. 17-11-01079).

■ MB-52

Monday, 10:30-12:00 - Virtual Room 52

EDDA 2

Stream: EURO Doctoral Dissertation Award
Award Competition session
Chair: *Hande Yaman*

1 - E-Commerce Warehousing: Order Fulfillment in Modern Retailing
Felix Weidinger

E-commerce led to drastic changes in end consumer behavior over the last decades. As a consequence, today's retailers often need to provide online channels to stay attractive and competitive. However, behind the online front-end, logistic processes are needed, capable of smoothly shipping small orders, picked from a large assortment in little time. These processes are complex and differ from classical warehousing processes to a large extend. The dissertation project presented summarizes today's challenges, surveys common implementations of e-commerce warehousing systems as well as related literature, and identifies new planning problems in modern e-commerce warehouses. A selection of novel planning problems from different domains and warehousing systems is investigated further. Based on mathematical models and complexity analyses, suited, tailor-made solution procedures are suggested, helping to tackle operational problems in these complex environments. In additional computational studies and simulation runs, strategic and tactical decision support is provided, considering feedback from the operational planning steps optimized. Managerial implications are part of each chapter, therefore. Additionally, problems are set in relation to classical warehousing operations. Emphasizing the differences to classical approaches, valuable insights into modern warehousing are given to researchers and practitioners.

2 - New Trends in Algebraic Equivalent Transformation of the Central Path and its Applications

Petra Renáta Rigó

The aim of the thesis is to propose, develop and analyse new interior-point algorithms (IPA)s. We also investigate the possibility of extending some IPAs from linear optimization (LO) to more general problems, such as linear complementarity problems (LCPs) and symmetric optimization (SO) problems. A large amount of articles have been published in this area. This is due to the fact, that these problems have a wide range of applications in different fields. It has been proven that the Nash equilibria of a bimatrix game are the same as the solutions of an appropriate LCP. The Karush-Kuhn-Tucker conditions of non-convex quadratic optimization problems lead to LCP, too. Moreover, LCP can also be used for testing copositivity of matrices. The Arrow-Debreu competitive market equilibrium problem with linear and Leontief utility functions can also be given as LCP. In general, LCP belongs to the class of NP-complete problems. However, Kojima et al. showed that if the problem's coefficient matrix has a special property, called $P_*(\kappa)$-property, IPAs for LCP have polynomial iteration complexity in the size of the problem and in the special parameter κ, called the handicap of the problem's matrix. The SO problem is a convex optimization problem, which minimizes a linear function over the intersection of an affine subspace and a symmetric cone. Note that SO includes semidefinite optimization (SDO) and second-order cone optimization (SOCO) and it has a lot of applications in physics, finance, etc.

In this thesis new results are included related to different areas of mathematical optimization, such as LO, LCP and SO. The leading thread through this work is the algebraic equivalent transformation (AET) technique in the context of IPAs. This method plays an important role in the theory of IPAs, because using it the representation of the central path is significantly modified, and this changes the location and the neighbourhood of the target points compared to the target points and neighbourhood corresponding to the original representation of the central path. As a consequence, we can define new search directions that yield new IPAs. The method of AET consists of applying a continuously differentiable and invertible function on the centering equation of the central path system. To our best knowledge, the broadest class of function used in the AET technique is due to Haddou et al., who introduced a family of smooth concave functions for monotone LCPs. One of the novelties of this thesis is that we apply the new function $\varphi(t) = t - \sqrt{t}$ on the centering equation of the system defining the central path. This function does not belong to the class of concave functions proposed by Haddou et al. We also show that the barrier associated to the introduced function cannot be derived from a usual kernel function. Therefore, we introduce a new notion, namely the concept of the positive-asymptotic kernel function. We also present the relationship of the AET technique to other approaches to determine search directions. Furthermore, we present four IPAs for solving different types of optimization problems that use this function in the AET technique in order to determine the new search directions. The first one is a classical primal-dual algorithm for LO. The second IPA is a predictor-corrector (PC) IPA for solving LO problems. The third new algorithm is also a PC IPA [1] for solving $P_*(\kappa)$-LCPs. In this part of our work we also give a unified framework of the Newton systems and scaled systems in case of PC IPAs for solving $P_*(\kappa)$-LCPs. The fourth new IPA solves SO problems and uses the same function in the AET technique in order to obtain the new search directions. In all four cases we present the complexity analysis of the proposed IPAs and we show that the methods retain the best known polynomial iteration complexity. Several questions remain open for future work. For instance, it would be very interesting task to find a general class of functions φ for AET which includes the function $\varphi(t) = t - \sqrt{t}$ and which gives IPAs with the best known complexity results for solving LO, $P_*(\kappa)$-LCPs and SO problems. Furthermore, we would like to extend our PC IPAs to more general problems, such as the general LCPs in the existentially polytime-sense and to sufficient LCPs over Cartesian product of symmetric cones.

■ MB-54

Monday, 10:30-12:00 - Virtual Room 54

Financial Reporting

Stream: Operational research in financial and management accounting
Invited session
Chair: *Sascha H. Moells*

1 - (Financial) Accounting Conservatism & Capital Markets - The Nexus of Book- to Market Values - A New Approach -

Tim Burger, Sascha H. Moells

Despite the growing importance of capital markets as a source of financing and the corresponding alignment of corporate disclosure with the interests of shareholders, potential accounting conservatism is still a key feature of financial accounting: While conservatism ("prudence") is typically perceived in terms of the opposed processing of good news versus the processing of bad news regarding the disclosed change in value of accounting items, the aforementioned imbalance might result in blurry performance indicators potentially impairing the efficiency of capital markets. While previous studies investigate conservatism focusing on the reaction of new information by means of examining the value of write-offs, we, in contrast, directly examine the value of balance sheet items, i.e. based on a more inclusive understanding of conservatism compare firm (market) values with book values of assets and liabilities. As a result of this comparison, we derive specific parameters allowing to redefine common valuation ratios as expressions to quantify conservatism. Building on this theoretical (regression) model, comparative empirical evidence enables us to analyze distinct accounting standards capturing the features of different underlying corporate governance systems. While first empirical results seem to confirm our theoretical reasoning, we are inclined to further address methodological issues to improve the scope of our novel approach.

2 - Impact of deferred taxes on the percentage of self-financing

Carolin Famulla

Deferred taxes are defined as expected futural tax payments respectively refunds, which arise because of temporary differences between the accounting and tax balance sheet, according to International Accounting Standard No. 12. Due to their temporary character, deferred taxes have a compensatory effect over the total period. During the individual periods deferred taxes affect the comprehensive income and equity with regard to the financial statement. According to the balance-sheet-oriented temporary-concept, deferred taxes relate to items recognised inside as well as outside profit and loss. In addition, deferred taxes have an impact on the percentage of self-financing as a selected key balance sheet figure. Thereby the relation between retained earnings and equity determines the percentage of self-financing. This key figure is a percentage measure for the permanent distributable income as a proportion of the equity. Depending on the resolution of the shareholders regarding to the appropriation of the net income deferred taxes affect the distributable income in different height. In consideration of the accounting discretion the effect of deferred taxes that are recognised inside and outside profit and loss is modelled on the percentage of self-financing over the duration of the underlying temporary differences. The presented approach shows the discretionary decisions on the recognition and measurement of deferred taxes in order to maximize the percentage of self-financing.

3 - Accounting standards precision and timeliness of accounting information: Evidence from China
Fei Song, Jianan Zhou

This paper addresses the role of principles-based accounting standards as a potential mechanism for reducing the time delay of annual reporting disclosure while improving the timeliness of accounting information. The paper also contributes to the existing literature by addressing the mediating effects of the financial reporting complexity and the audit workload on the link between principles-based accounting standards and the time delay of annual reporting disclosure. The results show the more principles-based the accounting standards are, the lower the time delay of annual reporting disclosure is, and the timelier the disclosure of accounting information is. The relationship between the two is more significant especially in the first two months after the end of the fiscal year. From the mediating effect results, we find that principles-based accounting standards decrease the financial reporting complexity and the audit workload which in turn can help lower time delay of annual reporting disclosure. In addition, the negative effect of principles-based accounting standards on the time delay of annual reporting disclosure is more significant in the case that the company has "good news" including with no losses and receiving the standard auditing opinions. The results of this paper have certain reference significance for accounting standards setters when formulating and revising the accounting standards, and also provide empirical evidence for auditors, investors and regulators.

4 - Impact of Systemic Risk Regulation on Optimal Policies and Asset Prices
Xuecan Cui

Although a few systemic risk management approaches have been proposed in the literature and implemented in the industry, such as stress tests based scenarios, the impact of such regulations remains unclear. In this paper, we present a theoretical framework to study the impact of systemic risk management on financial institutions' optimal policies and asset prices in equilibrium. Specifically, we study the impact of the conditional VaR (CoVaR) and Systemic Expected Shortfall (SES) constraints and illustrate the potential adverse effects of conditional risk measures given the market is under stress. We nd that a proper choice of the SES constraint, especially using information under risk neutral probability, may effectively reduce these effects.

Monday, 12:30-14:00

■ MC-01

Monday, 12:30-14:00 - Bulding A, Amphitheatre

Sustainable finance for the environment

Stream: AI & Innovation in Sustainable Finance
Invited session
Chair: *Rita D'Ecclesia*

1 - Emission Trading System: prices, reduction, and trade
Rita D'Ecclesia, Giacomo Morelli, Kevyn Stefanelli

The Emissions Trading System (ETS) is considered as one of the most cost-eective way to reduce polluting emissions. In this paper, we propose a mechanism design for the ETS and provide analytical characterization of equilibrium prices for polluting allowances that are determined by optimal trade and emissions reduction. We uncover achievements in meaningful reduction only through the aggregate effort of going low-carbon. To validate the analysis, we are able to replicate the European ETS showing the relevance of our results.

2 - Exploring Green Financial Opportunities
Kevyn Stefanelli

Green finance consists of a wide range of projects and investments aimed to ensure a better environmental outcome, in line with the Sustainable Development Goals. Several new financial instruments have been designed with the aim to have responsible or sustainable investments. However, the Green securities have been found to show different performances. In particular, the recent literature has been focusing on analyzing the advantage of investing in green bonds, make comparisons on the risk/return tradeoff of ESG rated companies, and analyze the performances of sustainable mutual and exchange-traded funds (ETF). In this paper, we aim to identify common features and various time horizons in environmentally responsible investments, in order to provide a taxonomy of the securities according to risk preferences and the chosen time horizon. We provide the investors with an accurate understanding of the various responsible investments traded on the market. We analyze sixty recent empirical works which deal with the modeling of responsible investments. We classify the results taking into account the i) country of analysis; ii) methodology used; ii) time frame iii) data used (monthly vs daily data); iv) methodology (structural or market analysis). We are able to classify the results according to the i) country of analysis (Europe, US, and rest of the world); ii) time frame (decades or shorter); iii) data used (monthly vs daily data); iv) methodology (structural or market analysis).

3 - A Global Gas Market Model for Risk Management: Effects of U.S.-LNG on Gas Markets in Western Europe
Maik Günther

Liquefied natural gas (LNG) plays an important role as a bridging technology to reduce CO2 emissions and has the world's largest growth potential among fossil fuels. In the last years, the U.S. constructed LNG export terminals and it is expected that they will further increase the liquefaction capacities. The costs of LNG exports are composed of the price for natural gas in the country of origin and the LNG process costs with liquefaction, transport, storage and regasification. Thus, the Henry Hub (HH) price in the U.S. is important for U.S. LNG exports to Western Europe. For asset valuation and risk management of a utility company the effects of price changes at HH on gas flows and gas prices in Western Europe are important to know. The gas market model WEGA is used for these to analyses. This LP model was developed with Xpress and optimizes global gas flows in daily resolution. The results of WEGA reveal that the price at HH has significant effects on U.S. LNG exports as well as on gas flows and gas prices in Western Europe. Especially pipeline gas in Western Europe will absorb fluctuations of U.S. LNG exports. Furthermore, analyses of gas prices show that U.S. LNG is exported below their long run marginal costs if the gas price at HH is too high. However, increasing gas prices at HH will not necessarily lead to one-to-one increasing gas prices in Western Europe, because there are other competitive sources available, e.g. from Qatar, North Africa and Russia.

■ MC-02

Monday, 12:30-14:00 - Bulding A, Room A5

Robust resource allocation and scheduling

Stream: Scheduling and Project Management
Invited session
Chair: *Izack Cohen*
Chair: *Shimrit Shtern*
Chair: *Krzysztof Postek*
Chair: *Gonçalo Figueira*

1 - Two-stage stochastic/robust scheduling using permutable operation groups: a constraint programming approach
Louis Riviere, Christian Artigues, Hélène Fargier

Even after being studied extensively, scheduling problems are still relevant today due to their wide range of concrete applications especially when considering uncertainty . We propose an efficient constraint programming approach for the computation of a flexible solution based on "permutable operation groups" with a simple second stage reordering policy; applied to a single machine problem with release dates, due dates, precedence constraints and aiming for the minimization of the maximum lateness over a sampled set of scenarios. We study the relative performance of this approach compared to a more classical single-schedule robust solution with shift repair policy. As group solutions dominate sequence solutions, the proposed approach should outperform the classical robust one, but given a limited search time, and the much larger size of the search space, it was unclear if the approach could perform better in practice. Results show that on smaller instances, or on instances with many considered scenarios and/or high inter-scenario variability, it can be advantageous to use the flexible solver. However, on more difficult, larger instances and instances with many precedence constraints, the single-sequence solver outperformed the flexible one.

2 - Robust Decision Tree for MMRCPSP
Tom Portoleau, Christian Artigues, Romain Guillaume

The consideration of uncertainty in scheduling problems has been extensively studied in the literature. Classically, two families of methods have emerged. Pro-active approaches aim at building robust schedules in an off-line phase, with a theoretical guarantee on the objective but which in practice produce very conservative solutions. On the contrary, reactive approaches compute new schedules on-line to quickly face uncertainties when they occur. The challenge of our approach is to build a robust decision tree that proposes to the decision-maker to adapt the current planning in an on-line manner to best respond to the current scenario. To build such a tree, we assume that there are so-called decision moments, moments during which the decision-maker is able to observe the planning process, to access information about the realisation of the scenario and to modify the current solution. However, it is possible that access to this information is expensive, and that not all information is relevant to improve the quality of the current solution. In order to select "good" information we model the information selection problem as an optimisation problem.To evaluate our trees, we compare ourselves to a reactive algorithm that uses the same information as them but in a random way. All tests are carried out on industrial instances. The aim is to show that the choice of relevant information allows for the computation of better quality solutions.

3 - Evaluating productivity metrics for dynamic scheduling problems
Gonçalo Figueira

Many real-world scheduling problems are dynamic, i.e., new information arrives continuously and implies frequent rescheduling. This was common in the past and will be even more in the future, with the dissemination of the Internet of Things in various domains. Nevertheless, these scheduling problems are often approached as static, especially in the presence of characteristics where pure online approaches tend to underperform, such as precedence constraints or sequence-dependent setups. The solution approach of these static problems is then incorporated in a rolling-horizon procedure, which periodically reschedules using new information. However, one issue that has been overlooked is that the metric to be optimized in the long-term is not necessarily a good objective function for each iteration of the rolling-horizon procedure. For instance, makespan, the most common productivity metric, will depend on the completion time of the last operation, but this becomes irrelevant in subsequent iterations as new orders arrive. We propose, analyse and simulate different productivity metrics for multiple dynamic scheduling problems, including single machine, parallel machine, job shop and flexible job shop. We show their relative performance in a variety of scenarios.

■ MC-03

Monday, 12:30-14:00 - Bulding A, Room 3A

Interactive Multiobjective Combinatorial Optimization

Stream: Multiobjective Combinatorial Optimization
Invited session
Chair: *Thibaut Lust*

1 - Interactive Multi-step Configuration Optimisation using Evolutionnay Algorithm and Constraint Programming
Elise Vareilles, Michel Aldanondo, Paul Pitiot, Abdourahim Sylla

Concurrent configuration activity of a system and its associated production process is a challenging problem in engineering. It gathers in a single problem multiple choices and constraints which come simultaneously from systems (choices of system's features and components), from processes (choices and allocation of resources) and from their relations. Its optimization, considering multiple objectives, such as cost, delivery date, carbon footprint, is thus a huge challenge in view of its complexity and combinatorial solution space.

We propose in this paper an interactive way to deal with user's preferences in concurrent configuration problems and to guide the optimization process.

A specific multi-objective optimization algorithm, named CFBEA (Constraint Filtering Based Evolutionary Algorithm) has already been proposed, combining evolutionary and constraint approaches for consistent individual generation. Based on CFBEA, the proposed interactive optimization runs into three steps. First, the user inputs his/her non-negotiable and essential features, such as system high/low power or forbidden resources. Second, a "rough" approximation of the Pareto Front is quickly searched and proposed to the user. Third, the area of the Pareto Front which is interesting for the user is identified (clearly delineated by thresholds on criteria), and a new optimization step is launched. Our interactive approach has been evaluated and is very competitive wrt competitive approaches.

2 - Local Search and Greedy Search Combined with Preference Elicitation for Maximizing Submodular Functions under Matroid Constraints
Cassandre Leroy, Nawal Benabbou, Thibaut Lust, Patrice Perny

We propose two incremental preference elicitation methods for interactive preference-based optimization on weighted matroid structures. More precisely, for submodular utility functions, we propose an interactive greedy algorithm interleaving preference queries with the incremental construction of an independent set to obtain a near-optimal base of a matroid. We also propose an interactive local search algorithm based on sequences of possibly improving exchanges for the same problem. Our algorithms are tested on the uniform and partition matroids to solve the maximum coverage problem and evaluated in terms of computation times, number of queries, and empirical error.

■ MC-04

Monday, 12:30-14:00 - Bulding A, Room 3B

Emerging Collaborative Economics and Management under Uncertainty 2

Stream: Emerging Collaborative Economics and Management under Uncertainty
Invited session
Chair: *Sırma Zeynep Alparslan Gök*
Chair: *Michal Cerny*

1 - Analyzing Dial-a-Ride systems in Austrian rural regions
Kerstin Maier, Philipp Armbrust, Philipp Hungerländer, Veronika Pachatz

The Dial-a-Ride Problem (DARP) asks for a minimal cost schedule for a set of customer requests served by a fleet of vehicles. Further restrictions, like time windows, pick-up and drop-off locations and capacity constraints are generally customary. A common example arises in passenger transportation, especially for elderly people or people with impaired mobility. In this work, we consider two different DARP systems employed by Austrian mobility providers. Both operators focus on rural regions and make use of a heterogeneous fleet of vehicles. Additional characteristics are for example the transportation of people with impaired mobility or break times for drivers. We consider two different optimization approaches, namely a Mixed-Integer Linear Programming approach and Large Neighborhood Search. In a computational study, we show different operator scenarios, like minimizing overall driven kilometers, number of used vehicles or the number of unscheduled requests, for up to 500 requests per day and 30 vehicles.

2 - Rebalancing via combinatorial optimization in a real life smart bike-sharing service.
Zisis Maleas, Georgia Ayfantopoulou, Josep Maria Salanova Grau, Panagiotis Tzenos, Andreas Nikiforiadis

This study deals with the bike-sharing problem. In particular, the authors present a rebalancing algorithm for a bike-sharing system in the city of Thessaloniki. The system that is optimized involves many important features like monitoring bike motion, data collection, data analysis and visualization, prediction, and redistribution. Authors developed a rebalancing algorithm based on combinatorial optimization with the use of pickup and delivery vehicle route problem (PDVRP). Based on FCD taxi data analysis that the authors made, near 40% of trips in the Municipality of Thessaloniki are less than 5km, and the fact that on average each trip duration increased by 30%, bike-sharing alternative it's not just a good option but also an emerging solution for the future sustainability of the city. The designed algorithm for PDVRP is a relaxation of the complete form of the primal problem. Our relaxation drops the sequence dimensions and considers only the connection among nodes. So the solution contains a list of variables that compose the path. In that, model capacity constraints included as well as a variable that decides the bike flow between the stations followed by continuity constraints and a tree search that returns the final solution. Finally, illustrated some methods that can handle that dynamic perspective along with precise implementation guidelines that could further improve bike-sharing services.

3 - Optimised management of a fleet of electric autonomous vehicles
Matthieu Bessoles, Pierre Hosteins, Paola Pellegrini, Joaquin Rodriguez

We propose to study a real-world problem where a public transport operator manages a fleet of electric autonomous vehicles on a public transport line. The line proposes a classic fixed timetable at peak hours. However, at off-peak hours, the line proposes an on-demand service, where the clients ask to be taken and brought anywhere along the line, with either a preferred departure or arrival time. We propose a Mixed Integer Linear Programming model for this problem, in order to maximise the level of service for the customers while minimising the fleet utilisation (and therefore costs). Since the shuttles travel on a dedicated infrastructure, we model the problem at the microscopic level, handling the occupation of the infrastructure by each individual shuttle, even handling the take over between shuttles. We will present some features of this MILP which are new to this type of problem and do not usually appear in guided transport traffic management (e.g. railways) or road transportation problems. Our model also handles the assignment of customers to shuttles and the possible charging of the shuttles at depots. We will discuss the limitation of our model in terms on realistic instances provided by the French company SNCF.

■ MC-05

Monday, 12:30-14:00 - Building Δ, Room Δ105

Analytic Hierarchy Process

Stream: AHP/ANP
Invited session
Chair: *Konrad Kułakowski*

1 - Similarity of ranking vectors in the pairwise comparisons method
Konrad Kułakowski, Jiri Mazurek, Michał Strada

There are many priority deriving methods for AHP. It is easy to prove that the ranking results do not depend on the adopted priority deriving method for the consistent set of pairwise comparisons. For an inconsistent matrix, however, the results usually differ. In the presented work, the authors try to determine a difference between priority vectors computed using two popular ranking methods: the eigenvalue method and the geometric mean method. The obtained estimate is based on the local inconsistency of the pairwise comparisons matrices. The authors complemented the theoretical considerations with the results of the Monte Carlo experiment.

2 - Efficiency and performance evaluation by AHP model: A comparison with traditional approaches
Josef Jablonsky

One of the most often applied approaches for relative efficiency evaluation is data envelopment analysis. The aim of the study is to propose a simple AHP model for evaluation of DMUs and compare the results with traditional models. AHP organises decision problems as hierarchical structures always containing several levels. The topmost level defines the goal of the decision problem which is the evaluation of the DMUs in our case. The next level contains decision criteria (inputs and outputs). This level can be structured into several particular sub-levels. The lowest level of the hierarchy describes alternatives (DMUs). The DMUs cannot be pairwise compared with respect to inputs and/or outputs directly because of possible significant differences among DMUs in their size and input and output values. That is why we suggest comparing them with respect to all ratios outputs/inputs which describe particular efficiencies of the DMUs. Depending on the number of efficient DMUs that are ranked either the AHP with relative measurement or absolute measurement can be used. The proposed approach is illustrated on a numerical example with a real-world background.

3 - Two spanning-tree-based inconsistency indices of pairwise comparisons matrices
Jacek Szybowski, Konrad Kułakowski, Anna Prusak

The pairwise comparisons method is a process of comparing object in pairs to obtain a ranking of alternatives. An algebraic representation of this process are pairwise comparisons matrices (PCMs). The inconsistency in judgements may be measured by different indices, e.g. Consistency Index (CI), Koczkodaj Index (KI), Geometric Consistency Index (GCI), or Harmonic Consistency Index (HCI). Most of these indices, however, measure the inconsistency only of complete PCMs, while it is often impossible or too expensive to compare each pairs of alternatives. Fortunately, to obtain the final ranking it is enough to have indirect comparisons between each alternatives. When we represent the set of comparisons as a graph, each spanning tree induces a ranking vector. In the case of a consistent PCM (complete or incomplete) this vector does not depend on the choice of a spanning tree. This simple observation leads us to the definition of two new inconsistency indices, which may be treated as deviations of weights vectors or order vectors resulting from different spanning trees of a pairwise comparisons graph. We call them the Manhattan Inconsistency Index (MII) and the K-Inconsistency Index (KII), respectively. In the presentation we give some examples of the calculation of MII and KII and discuss the correlation between them and other inconsistency indices using the Monte Carlo simulation.

■ MC-06

Monday, 12:30-14:00 - Building Δ, Room Δ103

Mixed Integer Linear Programming for transportation problems I

Stream: Mixed Integer Linear Programming
Invited session
Chair: *Carlo Mannino*
Chair: *Mohammad Reihaneh*

1 - Dynamic Airspace Configuration in 5 minutes combining deep nets and unconstrained optimization
Giorgio Grani, Carlo Mannino, Patrick Schittekat

Dynamic airspace configuration (DAC) is the problem of identifying a suitable partition of the airspace to guarantee the best workload imbalance for air traffic controllers, dynamically adjusted to consider the current traffic. Changing the shape of control sectors through time has gained increased interest among European countries. The problem has been mostly addressed by employing genetic algorithms on a daily horizon, making it impractical for optimizing over a finer time window. Ideally, the sectors should change dynamically not less than every half an hour, exploiting different scenarios, leaving small time for the optimization. In this work, we present DAC-AI, a novel procedure that uses a deep neural network as an estimator for the complexity drivers. Once the training has concluded, DAC-AI imposes a fixed connection structure in the form of a graph, and finally, it optimizes the average imbalance by first-order unconstrained optimization. The deep model is composed of two incidental LSTM networks, handling multiple trajectories. The procedure is supported by two heuristics, one for merging and the other for splitting respectively, which use the deep estimator in a greedy fashion. The algorithm has an average response time smaller than five minutes for medium-sized airspaces. This work is part of a study conducted by SINTEF and the Italian airspace regulator (ENAV). Preliminary tests have been conducted over the Milan flight information region.

2 - Design Factors for Optimized Railway Dispatch Under European Operating Rules
Steven Harrod, Giuseppe Matera

Multiple trials of railway traffic management systems incorporating mathematical programming have successfully completed in the last five years. Multiple railway infrastructure managers have announced tenders or projects for implementation of larger scale systems that are intended to be long term commitments. In this presentation, Dr. Harrod presents insights collected from other transport modes and other large scale industrial planning systems. How does a commercial implementation of optimized dispatch differ from the experimental trials of academic research?

European Union law sets very specific expectations and limits on how railway infrastructure managers must serve train operating companies. These expectations are also found in national laws of the EU member states. Dr. Harrod proposes a possible multi-level decision structure based upon methods from airline traffic control. The objective is to achieve the transparent and neutral dispute resolution of conflicting trains required by EU law.

3 - The Berth Allocation and Quay Crane Assignment Problem considering crane movement and setup times
Juan Correcher, Federico Perea, Ramon Alvarez-Valdes

Container terminals are the main gates for goods all over the world. Both maritime and in-land transportation rely upon the efficient management of cargo in ports and thus competence between terminals puts pressure on their operations. The planning process in the quayside involves assigning each calling vessel a berthing time, a position on the quay and the specific cranes that will serve it once arrives at the berth, aiming at minimizing the overall cost of the terminal. In the scientific literature, this is known as the Berth Allocation and Specific Quay Crane Assignment Problem (BACASP). Most approaches to this problem published up to date consider that both the movement time of the cranes between vessels and their setup time is negligible. However, in reality these time periods may affect the berth plan, even unleashing a domino effect. To take them into account, we develop a new mixed integer linear programming model and conduct several experiments to assess its performance and the effects of crane times.

4 - A branch-and-price algorithm for the redundancy allocation problems
Mohammad Reihaneh, Mostafa Abouei Ardakan, Majid Eskandarpour

The redundancy allocation problem (RAP) is one of the most commonly used approaches for improving the reliability of systems. The present study proposes an exact branch-and-price (BP) algorithm for the RAP with heterogeneous components under the mixed redundancy strategy. The proposed algorithm solves in less than one CPU second all the benchmark instances reported in the literature. The algorithm is not only the first exact one proposed for the RAP with a mixed strategy but also the first application of the BP algorithm in the literature of reliability optimization problems. Finally, a new set of instances is generated to evaluate the performance of the proposed algorithm in dealing with more challenging instances.

■ MC-21

Monday, 12:30-14:00 - Virtual Room 21

General papers

Stream: Descriptive and prescriptive behavioural OR studies
Invited session
Chair: *L. Alberto Franco*

1 - Leadership in participatory modelling - Is there a need for it?
Raimo P. Hämäläinen, Iwona Miliszewska, Alexey Voinov

Leadership is the first and essential focus when performance of any organization in the public and private sectors is considered. There can be no organizational activity without leadership and/or management. The same is true for OR projects. The paper introduces the concept of leadership into the context of participatory modelling. The relevance of different leadership paradigms is discussed. The leadership and management perspectives are compared. The role of the modeler and the question who should be assigned the leadership role is analyzed. Often the OR/PM project is initiated by a modeler who has specific technical skills and expertise in a particular modelling method. Thinking that a model can solve problems by merely being implemented can be a persisting one. However, modelling is a process which involves more than the technicalities of the model. The leadership function assumes seeing the big picture and setting the right goals as well as reflecting on technical, resource and behavioral factors that may affect the overall process. In participatory modelling the project team usually includes people having very different roles and backgrounds. Some people need to have strong technical modelling skills, some need to be project managers and some need to have good social and facilitation skills. Political skills may also be needed to keep the project funded and stakeholders interested and motivated.

2 - IoT's effect on psychological ownership of employees: The mediating role of process-orientation
Hannes Reil, Michael Leyer

The growing number of objects with Internet of Things (IoT) functions in workplaces allows organizations to focus more on their processes. Employees can have a higher individual process orientation which is expected to increase their feeling of psychological ownership for the workplace. But it can also give them a feeling of being agents of the technology which is dominating more how the processes are executed. While there is research on psychological ownership regarding the acceptance and use of IT, not much exists on how the implementation and perception of IT-environments such as IoT impacts employees' psychological ownership. Therefore, we aim to answer the question of how IoT affects psychological ownership. Additionally, as IoT-objects are integrated into work processes, we analyze how an individual's process orientation mediates the relationship between IoT and psychological ownership. We surveyed 492 employees regarding experiences in their workplace. Our results show that two out of three dimensions of IoT affect psychological ownership via the mediator, one is having a direct influence. Moreover, there is a positive influence of the number of IoT objects on the shared feeling of psychological ownership. The results demonstrate that IoT usage leads to an enhanced shared feeling of responsibility for the own workplace. Our results contribute to the understanding of how technology is impacting the perception of employees in terms of shared operational responsibility.

3 - Taking stock of Behavioural OR studies
L. Alberto Franco, Etienne Rouwette, Raimo P. Hämäläinen, Ilkka Leppanen

This review maps the body of behavioural OR studies that focus on process. We surveyed the relevant OR literature covering a 30-year period, and identified two types of studies, each exhibiting different assumptions about behaviour (determinist or voluntarist) and concerned with different research questions. By categorising studies in this way, four empirically-generated knowledge themes emerge: model building, user engagement, OR as performance, and OR as activity. Each of these knowledge themes provides important insights into the behavioural factors that affect, or are affected by, the conduct of OR-supported interventions. We conclude our review with suggestions for further developing the behavioural OR agenda concerned with process.

4 - The effect of experience and learning on ordering decisions
Neslihan Özlü

Supplier lead times are considerably variable. Drawing on transaction-level purchasing data from a large European manufacturer, we investigate the purchasers-ordering behaviour under variable lead times. In particular, we examine the learning of the purchasers through their experiences with the suppliers. We differentiate between purchasers according to their experience level, which is a measure of the number of encounters with the suppliers. Our analysis reveals that the prior delivery performance of the supplier affects safety times, while the purchaser experience, moderates this effect of the prior delivery performances. We further explore peer's effect on the purchaser's decisions to add safety times to ensure on-time delivery. We also explore the heterogeneous effects, such as specific purchasers versus specific suppliers or all suppliers. We observe the peer effect on the decisions of the purchasers, additionally and more interestingly different responses to specific versus overall suppliers. Furthermore, while learning from their past experiences, purchasers put more weight on the latest interaction.Counter-intuitively, more experienced purchasers tend to be more sensitive to the most recent encounter when compared with their less experienced colleagues. Our results have implications for supplier relationship management and highlight the role of the experience of the purchasers for efforts to optimise ordering decisions.

■ MC-22
Monday, 12:30-14:00 - Virtual Room 22

On some extensions of Stackelberg games

Stream: Bilevel Optimization
Invited session
Chair: *Ludovic Julien*
Chair: *Olivier Musy*

1 - Noncooperative equilibrium in markets with hierarchical competition
Ludovic Julien

Abstract: This paper deals with the existence of a non-cooperative sequential equilibrium in interrelated markets with heterogeneous atomic traders. Since this model features a rich set of strategic interactions, there are two kinds of problems associated with the existence of equilibrium. First, existence and uniqueness of followers' strategies are not guaranteed. Second, the no-trade equilibrium is always an equilibrium outcome. To overcome these two difficulties we consider a differentiable approach. We show that the set of equations which determines the strategies of followers is a variety with the required dimension, i.e. the vector mapping which defines this set is a local C'-diffeomorphism. The continuous differentiability of followers' strategies is critical for the existence of an interior equilibrium. Unlike the simultaneous move games, exchange can take place in one subgame while autarky can hold in another subgame, in which case only leaders (followers) make trade. Some examples buttress the approach and discuss the assumptions made on the primitives.

(Author: Ludovic Julien) Speaker: Ludovic Julien (University Paris Nanterre)

2 - On Stackelberg-Nash equilibria in bilevel optimization games
Olivier Musy

Hierarchical games with strategic interactions such as the Stackelberg two-stage game epitomize a standard economic application of bilevel optimization6problems. In this paper, we survey certain properties of multiple leader-follower non-cooperative games, which enable the basic Stackelberg duopoly game to encompass a larger number of decision makers at each level. We focus notably on the existence, uniqueness and welfare properties of these multiple leader-follower games. We also study how this particular bilevel optimization game can be extended to a multi-level decision setting.

(Authors: Damien Bazin, Ludovic Julien, Olivier Musy) Speaker: Olivier Musy (University of Paris Descartes)

3 - Pollution in strategic multilateral exchange: taxing emissions or trading on permit markets?
Anicet Kabre

We introduce polluting emissions in the sequential bilateral oligopoly model with a productive sector of Julien and Tricou (2012), which extends the bilateral oligopoly model with a finite number of traders of Gabszewicz and Michel (1997). Within this two-sector framework, we consider a polluting technology which produces one commodity which creates negative externalities. By modelling emissions as a negative externality, we show notably that the leader pollutes more (less) than her direct follower in the presence of strategic substituability (complementarity). Then, we study two kinds of regulation to control the levels of emissions, namely, two taxation mechanisms and a permits market. By comparing the two kinds of policies, we show that the effectiveness of public policies regarding the regulation of emissions depends on the preferences of agents toward the polluting commodity.

(Authors: Ludovic Julien, Anicet Kabre, Louis de Mesnard) Anicet Kabre (World Bank Group-Africa Fellow)

■ MC-23

Monday, 12:30-14:00 - Virtual Room 23

Recent Advances in Derivative-free Optimization I

Stream: Derivative-free Optimization
Invited session
Chair: *Ana Luisa Custodio*
Chair: *Francesco Rinaldi*

1 - Direct-Search for a Class of Stochastic Min-Max Problems
Youssef Diouane, Sotiris Anagnostidis, Aurelien Lucchi

Recent applications in machine learning have renewed the interest of the community in min-max optimization problems. While gradient-based optimization methods are widely used to solve such problems, there are however many scenarios where these techniques are not well-suited, or even not applicable when the gradient is not accessible. We investigate the use of direct-search methods that belong to a class of derivative-free techniques that only access the objective function through an oracle.

In this talk, we present a novel algorithm in the context of min-max saddle point games where one sequentially updates the min and the max player. We prove convergence of this algorithm under mild assumptions, where the objective of the max-player satisfies the Polyak-Lojasiewicz condition, while the min-player is characterized by a nonconvex objective. Our experimental results establish that direct-search can outperform traditionally adopted optimization schemes, while also presenting a promising alternative for categorical settings.

2 - A Derivative-free Method for Structured Optimization Problems
Francesco Rinaldi, Andrea Cristofari

Structured optimization problems are ubiquitous in fields like data science and engineering. The goal in structured optimization is using a prescribed set of points, called atoms, to build up a solution that minimizes or maximizes a given function. In this talk, we want to minimize a black-box function over the convex hull of a given set of atoms, a problem that can be used to model a number of real-world applications. We focus on problems whose solutions are sparse, i.e., solutions that can be obtained as a proper convex combination of just a few atoms in the set, and propose a suitable derivative-free inner approximation approach that nicely exploits the structure of the given problem. This enables us to properly handle the dimensionality issues usually connected with derivative-free algorithms, thus getting a method that scales well in terms of both the dimension of the problem and the number of atoms. We analyze global convergence to stationary points. Moreover, we show that, under suitable assumptions, the proposed algorithm identifies a specific subset of atoms with zero weight in the final solution after finitely many iterations. Finally, we report some numerical results showing the effectiveness of the proposed method.

3 - BFO 2.0: A New Release of the Brute Force Optimizer that Merits its Name a Little Bit Less
Margherita Porcelli, Philippe L. Toint

The talk shortly reviews some of new features of the derivative-free optimizer BFO Matlab package. Among these, several important new problem-oriented features will be discussed: * Using coordinate partially-separable problem structure. This ubiquitous problem structure can now be exploited by BFO, leading to very significant gains in performance (orders of magnitude) also allowing the use of BFO for large problems (several thousands of variables). * The BFOSS library of model-based search steps. It is a BFO-compatible library whose purpose is to compute interpolation-based search steps. BFOSS supports model building for objective functions given in coordinate-partially-separable form. This combination provide even further significant performance improvements. * Categorical variables. BFO now supports the use of categorical variables. Categorical variables are unconstrained non-numeric variables whose possible 'states' are defined by strings (such as 'blue'). * Performance and data profile training strategies. Because BFO is a trainable package, it needs to define training strategies which allow to decide if a particular option is better than another. BFO now includes new training strategies based on performance profiling and data profiling.

BFO Release 2.0 is available at https://github.com/m01marpor/BFO free of charge.

■ MC-24

Monday, 12:30-14:00 - Virtual Room 24

Recent Results in Global Optimization 2

Stream: Global Optimization
Invited session
Chair: *Syuuji Yamada*

1 - Dual Cutting Plane Method for Nonconvex Optimization
Jaehwan Jeong, Chanaka Edirisinghe

We propose a new dual cutting plane (DCP) technique for computing the Lagrangian dual bound efficiently in nonconvex optimization. The DCP method transforms the dual feasible domain into a compact set, which is iteratively redefined using optimality cuts that shrink the dual space successively. Such a technique contrasts with the usual step-size-based search methods found in subgradient optimization that are slow to converge with potential tailing-off effects. Moreover, the DCP method does not rely on (sub) differentiability of the functions, and it only requires the solution of an optimization sub-problem with simple constraints, such as variable bounds. The computational efficiency of the proposed method is, however, dependent on the number of constraints that are Lagrangian-relaxed. We perform computational experiments using randomly-generated instanced to demonstrate the scalability of the approach as the number of variables grows substantially, but the number of nonconvex constraints is limited, in comparison to the available standard methods.

2 - An Exact Solution Method for Concave Minimization Problems
Arka Das, Ankur Sinha, Guneshwar Anand, Sachin Jayaswal

We propose an exact algorithm for solving mixed-integer concave minimization problems. The algorithm iteratively approximates the concave objective function with piecewise linear inner-approximation. The substitution of the concave function with a piecewise linear function converts the original optimization problem into a bilevel program that represents the lower bound of the original problem. The bilevel problem is solved by reducing it to a single level formulation using Karush-Kuhn-Tucker (KKT) conditions. This lower bound program, when solved iteratively with refinements in inner-approximation at each iteration, guarantees convergence to the global optimum of the problem. Though the algorithm is general, i.e. it can be applied to any concave minimization problem, we solve two common classes of concave minimization problems to test the computational efficiency of our algorithm. They are the concave knapsack problem and the concave production-transportation problem. The computational experiments indicate that our method outperforms the recently proposed approaches by an order of magnitude while solving the two classes of problems.

3 - A global optimization algorithm incorporating a procedure of listing KKT points for a quadratic fractional programming problem
Syuuji Yamada

In this study, we consider a quadratic fractional programming problem (QFP) to minimize the ratio of two quadratic convex functions over a convex set defined by quadratic convex functions. It is known that fractional programming is one of the typical problems in Global Optimization. Several types of iterative methods for solving (QFP) have been proposed by many researchers. However, such algorithms are not effective in the case where the dimension of variables is so large. One of the difficulties in solving (QFP) is the complexity of the objective function. Hence, in order to overcome this drawback, we transform (QFP) into a parametric quadratic dc programing problem (QDC) minimizing a quadratic dc function over a convex set. Moreover, to find an approximate solution of (QDC), we introduce an algorithm for listing KKT (Karush-Kuhn-Tucker) points of (QDC). Since every locally optimal solution of (QDC) satisfies KKT conditions, we can calculate most of locally optimal solutions contained in the intersection of the boundaries of convex sets defining the feasible set by utilizing our algorithm. Furthermore, to improve calculation efficiency, we incorporate our algorithm into a branch-and-bound procedure for Lagrange multipliers of constraint functions. The proposed algorithm can calculate an approximate solution of large scale (QFP). The effectiveness of the proposed algorithm has been shown by the result of the computer experiment.

■ MC-25

Monday, 12:30-14:00 - Virtual Room 25

Novel Methodologies for Energy Trading under Uncertainty

Stream: Stochastic and Robust Optimization
Invited session
Chair: *Bruno Fanzeres*
Chair: *Andrew Rosemberg*

1 - Hedging Price and Volume Risk in Renewable Energy Trading: A Soft Robust Portfolio Allocation based Approach
Bruno Fanzeres, Arthur Brigatto

Within competitive electricity markets, supply contracts play an important role. They help ensure supply adequacy and mitigate market power, among other benefits. However, when renewable energy is involved, the mixture of an uncertain energy production with a high volatile short-term market poses a risk difficult to manage. Within this context, call/put options are suitable hedging instruments to cover production imbalance with respect to supply contracts. To efficiently balance the cost/benefit of a set of energy options in a portfolio of renewable sources short in supply contracts, a precise definition of the probabilistic nature of the short-term market price should be available. However, it is recognized that in practice agents only have an imprecise approximation of the "true" underlying process. Thus, decisions are made under ambiguity. Therefore, the standard pure stochastic approach for the optimal composition of electricity contracts may not be suitable. In this work, we propose a risk- and ambiguity-constrained portfolio allocation model that defines the optimal composition of call/put options and renewable sources to back a supply contract. A case study with realistic data from the Brazilian power system is presented aiming at illustrating the applicability and efficiency of the proposed methodology in hedging price and volume risk in renewable energy trading.

2 - A Two-stage Model on Optimal Location and Operation of Waste-to-Energy Plants: Influence of Waste Composition Uncertainty
Dušan Hrabec, Jaroslav Pluskal, Radovan Šomplák, Vlastimír Nevrlý, Lars Magnus Hvattum

Waste management is geared towards a circular economy with the aim to increase the sustainability of the system by reducing waste production, reduce landfilling and increasing recycling. More efficient management of municipal waste thus leads to higher material utilisation. On the other hand, high recycling is associated with the formation of residual waste flows that represent a significant energy potential. The composition of waste is very variable. However, it has a major effect on energy amount from its recovery. To ensure the operability and economic sustainability of Waste-to-Energy (WtE) plants, a real change in the composition of the waste must be considered. The energy amount, which could be obtained from waste recovery, varies between waste producers and should be included in strategic decisions. Herein, a two-stage stochastic mixed-integer linear programming model is developed to support strategic capacity planning for waste energy recovery. It captures waste composition uncertainty and allows to include several scenarios of possible future development. The first stage decision suggests the location of WtE capacities, while the second stage includes the solution of the proposed scenarios. The developed approach is applied to the case study in the Czech Republic for waste management in 2030. The result suggests to build 13 WtE plants to support 4 already existing which increases the annual treatment capacity by almost four times and satisfies EU directives.

3 - Multistage Scenario Trees Generation for Electricity Markets Optimization
Marlyn Dayana Cuadrado Guevara, F.-Javier Heredia

The presence of renewables in electricity markets optimization have generated a high level of uncertainty in the data, which has led to a need for applying stochastic optimization to model this kind of problems. In this work, we apply Multistage Stochastic Programming (MSP) using scenario trees to represent energy prices and wind power generation. We developed a methodology of two phases where, in the first phase, a procedure to predict the next day for each random parameter of the MSP models is used, and, in the second phase, a set of scenario trees are built through Forward Tree Construction Algorithm (FTCA) and a modified Dynamic Tree Generation with a Flexible Bushiness Algorithm (DTGFBA). This methodology was used to generate scenario trees for the Multistage Stochastic Wind Battery Virtual Power Plant model (MSWBVPP model), which were based on MIBEL prices and wind power generation of a real wind farm in Spain. In addition, we solved three different case studies corresponding to three different hypotheses on the virtual power plant's participation in electricity markets. Finally, we study the relative performance of the FTCA and DTGFBA scenario trees, analysing the value of the stochastic solution through the Forecasted Value of the Stochastic Solution (FVSS) and the classical VSS for the 366 daily instances of the MSWBVPP problem spanning a complete year.

4 - Bilevel Optimization And Automatic Dualization Applied To Power Systems
Guilherme Bodin, Joaquim Dias Garcia

In this talk, we present two extensions to the JuMP environment of mathematical programming in Julia and its applications to power systems. The first extension is Dualization.jl; the package can automatically dualize any conic convex optimization problem. Automatic Dualization can be used to model bilevel problems by building KKT conditions, which leads us to the second extension: BilevelJuMP.jl.

This package makes it straightforward for users to write bilevel problems just like JuMP made it easy to write optimization problems. BilevelJuMP.jl has multiple formulations for complementarity constraints such as SOS1, Fortuny-Amat, quadratic programming, and actual complementarity constraints. We show how the packages were developed, relying on Julia the JuMP infra-structure, and we present some power systems examples of bilevel problems

■ MC-26

Monday, 12:30-14:00 - Virtual Room 26

Organizational, social, and cognitive aspects in applying data-based decision analysis

Stream: Decision Analysis and Decision Analytics
Invited session
Chair: *Pavlos Delias*

1 - Market Segmentation Of Products Offered With Shared-Service Contracts and Predictive Technology

Amit Joshi

Customers accepting "shared-service contracts", where OEMs take a pre-decided share of the products' long-term failure opportunity costs, are a standard feature of long-life, capital-intensive products. OEMs also increasingly use predictive technology to enhance service productivity while executing service contracts to reduce the long-term failure opportunity cost and drive better products through data generated by such technology. A significant drop in the cost of predictive technology and its allied service productivity benefits are increasingly moving OEMs towards shared-service contracts.

We study the market segmentation of products offered with shared-service contracts and predictive technology using an adverse selection model that incorporates: (i) The cost of product development and operation, (ii) The OEM's share of the failure opportunity cost driven by the product failure rate and the product quality, and (iii) The cost of incorporating predictive technology which reduces the two cost components. We postulate two product offerings from the OEM, a basic offering and a premium offering targeted at their respective customer types while incorporating the customer's share of the failure opportunity cost.

We find that shared-service contracts hinder an OEM's ability to segment markets with the high segment product's long-term failure opportunity cost being a key driver. The adoption of predictive technology, however, enables segmentation and high-quality products.

2 - Concordance Analysis and Visualization in Partial Orders with Ties

Antonio Carlos Santos Junior, Esteban Fernandez Tuesta

Researchers have long sought measures for agreement on judgments about objects or subjects related to specific attributes. This research project aims to develop a model for concordance analysis and visualization, considering partial orders with ties among judgments. The modeling proposed in this study is based on an affiliation network, in which people are connected to each other through a membership relation. In general, affiliation networks are constructed from a set of actors and a set of social events, where each actor is said to participate in one or several events. An affiliation network can be naturally represented as a bipartite graph, with each node representing either an actor or an event. An edge represents the participation of an actor in a specific event. In proposed model, judges and evaluated objects are represented as disjoint subsets and the edges are represented as the decision of each judge regarding each object. One reason for this study is that there is a lot of information to discover between individuals by considering the events that they share, and likewise, correlation between events can be discovered by considering the shared participation by actors.

■ MC-27

Monday, 12:30-14:00 - Virtual Room 27

Choice-Based Optimization

Stream: Analytics in Service Management
Invited session
Chair: *Sven Müller*
Chair: *Lorena Reyes-Rubiano*

1 - Sustainable product design when durability matters - with applications to the case of electric toothbrushes

David Topchishvili, Cornelia Schoen

Many examples illustrate the general trend of shorter product lives in the electronics industry (e.g., Bakker et al. 2014, Basulto 2012). The resulting impacts on the environment are manifold. At the same time, the impact from a purely economic perspective is unclear. Shorter product lives may influence both, the revenues as well as the costs of a company in positive as well as negative way.

Our paper questions the advantageousness of physical obsolescence practices form revenue perspective. In particular, we believe that product lives have become too short. To investigate this hypothesis, we develop an optimization model that explicitly accounts for durability as a determinant product attribute. Further, we conduct a consumer survey to estimate choice model parameters. As a case example, we focus our attention on the under-researched product category of electric toothbrushes. Initial results of our survey indicate strong importance of the durability attribute for consumers.

The contribution of the paper is threefold. First, the paper provides a prescriptive product (line) design model whose analysis provides insight into the potentially non-monotonic relationship between durability and profitability. Second, the paper derives design recommendations specifically for electric toothbrushes. Third, the paper bridges the fields of problem-centered prescriptive analytics and data-centered predictive analytics.

2 - Constrained Assortment Optimization Under the Mixed Logit Model with Design Options

Sven Müller, Knut Haase

We present the constrained assortment optimization problem under the mixed logit model (MXL) with design options and deterministic customer segments. The rationale is to select a subset of products of a given size and decide on the attributes of each product such that a function of market share is maximized. The customer demand is modeled by MXL. We develop a novel mixed-integer non-linear program and solve it by state-of-the-art generic solvers. To reduce variance in sample average approximation systematic numbers are applied instead of pseudo-random numbers. Our numerical results demonstrate that systematic numbers reduce computational effort by 70%. We solve instances up to 20 customer segments, 100 products each with 50 design options yielding 5,000 product-design combinations, and 500 random realizations in under two minutes. Our approach studies the impact of market position, willingness-to-pay, and bundling strategies on the optimal assortment.

3 - Tariff Zone Planning for Public Transportation

Lorena Reyes-Rubiano, Sven Müller, Knut Haase

The tariff system greatly determines the expected revenue of public transportation. This paper presents two approaches to design a counting zones tariff system applicable for urban public transport service providers. The proposed approaches are oriented to a counting zones tariff system that maximizes the expected revenue for a given price system. It is assumed that the price per zone takes a discrete set of values, the number of public transport trips depends on the price system, public transport passengers always choose the time-shortest path. The exact method aims to partition the transport network into zones and find a price per zone such the total expected revenue is maximized. The heuristic approach reduces the problem size; it only considers transport network connections with the most significant revenue. In extensive numerical studies with artificial test instances, it is evaluated for different network structure and public transport demand which of the proposed approaches perform best. This paper sheds light for service providers on how the service area can be zoned to maximize expected revenue through a counting zones tariff system.

■ MC-28

Monday, 12:30-14:00 - Virtual Room 28

Data Science and Analytics - Finance, efficiency and security

Stream: Data Science and Analytics (contributed)
Contributed session
Chair: *Nouri (Nourhan) Sakr*

1 - Investment Efficiency Analysis of European Education and Health Sectors
Edo Omic, Etleva Gjonca

In recent years policymakers throughout Europe have been determined to enact strategies and investment plans that will strengthen their respective public social sectors. To help guide future investments, this paper aims to examine two of those sectors, education and health, and how efficient past investment levels have been in achieving desired social outcomes. We use panel data sets and employ Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA) models to study the investment efficiency change in the education systems of 33 Europe countries (plus 10 advanced, non-European countries) from 2012 and 2015, and in the health systems of 34 European countries from 2011 to 2016. To capture optimal outcomes for each sector, we utilise a country's average PISA score for the education sector and the number of avoidable deaths for the health system; our primary input variables of interest are public expenditure on education per student (for education analysis) and health expenditure as a percentage of GDP (for the health analysis). We find that in the education system, the efficiency of investments between 2012 and 2015, on average, did not substantially improve in both DEA and SFA models. Meanwhile, in the healthcare system, we find that investment efficiencies between 2011 and 2016, on average, have been improving in both the DEA (Malmquist index) and SFA models. The paper also examines a number of environmental inputs as well as country-specific control variables.

2 - Development of a data-driven application to depict the socioeconomic effects of transportation
Dimitrios Dimitriou, Maria Sartzetaki, Aristi Karagkouni

Transportation and economic development interact with each other as transport makes significant direct and indirect contributions to the economy and increases the cycle of economic activity. Key objective of the paper is to present the architecture a data-driven (AI) application to provide quantitative estimations on the socioeconomic effects of transportation in regional business ecosystem. The competitive business environment, and unconditional uncertainties (eg COVID-19 pandemic) are key drivers for implementing dynamic assessment tools to support from short corporate decision to long time plans such as investments and capital-intensive projects. Therefore, estimating the socioeconomic contribution of transport sector, lead to great interest for introducing a new generation of data-driven, interactive and dynamically adaptive tools to support decisions from new capex investments and strategic planning up to short term allocation of resources and opex management in transport sector. The case study is formulated to illustrate results in air transport infrastructure operators.

3 - Methods for reducing the number of alerts about fraudulent transactions in the bank
Kseniia Ilchenko

Anti-money laundering is one of the top questions of the financial system. On the operational level, the detection of a fraudulent transaction in a bank is based on the scenarios that describe the sets of normative rules and statistical dependences. The transactions that suspect to be fraudulent should be checked additionally and then, the verified potentially fraudulent transactions should be transmitted to the corresponding authority for approval. The potential alerts are collected with a low level of precision. Thus, the goal of the research is to decrease the number of false alerts by keeping the positive alerts that correspond with the detected fraud. Based on TPOT analysis, the RandomForestClassifier, ExtraTreesClassifier and GaussianNB, and BernoulliNB were chosen for comparison. As the additional techniques, Probability Calibration and Stacking are used to increase the quality of the results. Taking into account, that the data set is imbalanced and the computation resources are limited, three methods, Cluster-based undersampling, NearMiss, and BalancedRandomForestClasifier were investigated. The unsupervised learning models for anomaly detection were presented by IsolationForest, OSVM, RobustCovariance, and LOF. The results of IsolationForest could be taken into consideration, however, the supervised learning models give better performance. The chosen method allows decreasing the number of alerts by 10-15%.

4 - Combinatorial Scheduling for Adaptive Machine Learning in Cybersecurity
Nouri (Nourhan) Sakr, Cynthia Phillips, Ojas Parekh, Clifford Stein

In this paper, we study two different applications in cybersecurity: an adaptive ML problem and a game-theoretic model called PLADD. The common objective between both problems is to protect cybersystems against attacks by intelligent, adaptable and well-resourced adversaries while maintaining a cost budget. We introduce a novel combinatorial scheduling formulation to design useful defense strategies that meet this goal. Our work separates the formulation from the data-driven analysis and solution. As such, the scheduling formulation, which does not resemble any previously studied formulations from the scheduling literature, may be used as a new model by other researchers for different motivations. We keep the model generic enough for others to use, but design the algorithms that work best for our context and data. The formulation is inspired by stochastic programming and cast as a mixed integer program (MIP). We provide theoretical analysis, e.g. explore integrality gaps, exploit the combinatorial structure, prove NP-hardness, develop dynamic programming solutions for two-machine cases, then work towards data-driven heuristics using distribution assumptions and real data from Sandia National Labs.

■ MC-29

Monday, 12:30-14:00 - Virtual Room 29

Dynamics and Games 2

Stream: Dynamics and Games
Invited session
Chair: *Alberto Pinto*

1 - On one type of stability in finite games with perturbed payoffs
Yury Nikulin, Vladimir Emelichev

We consider a finite cooperative game of several players in a normal form with perturbed linear payoffs where perturbations formed by a set of additive matrices, with two arbitrary Hölder norms specified independently in the outcome and criterion spaces. The concept of equilibrium is generalized using the coalitional profile, i.e. by partitioning the players of the game into coalitions. In this situation, two extreme cases of this partitioning correspond to the Pareto optimal outcome and the Nash equilibrium outcome, respectively.

We analyze such type of stability, called strong stability, that is under any small admissible perturbations the efficiency of at least one optimal outcome of the game is preserved. The attainable upper and lower bounds of such perturbations have been specified. The obtained results generalize some previously known facts and shed more light on the combinatorial specific of the problem considered.

2 - The Pareto optimal balanced exchange problem
Michalis Samaris, Pavlos Eirinakis, Yiannis Mourtos

We investigate a market without money in which agents can offer certain goods (or multiple copies of an agent-specific good) in exchange for goods of other agents. The exchange must be balanced in the sense that each agent should receive a quantity of good(s) equal to the one she transfers to others. In addition, each agent has strict preferences over the agents from which she will receive goods, and there is an upper bound on the volume of each transaction and a weight reflecting its social importance or its cardinal utility for the two agents. We propose a simple variant of the Top Trading Cycles mechanism that finds a Pareto optimal balanced exchange. We then offer necessary and sufficient conditions for a balanced exchange to be Pareto optimal and exploit these to obtain a recognition procedure. This procedure can detect whether a given exchange is Pareto optimal and, if not, improve it to become Pareto optimal in polynomial time. Last, we show how to obtain a Pareto optimal balanced exchange of maximum weight in two special cases.

3 - Bidding in procurement auctions with the co-operation of a local agent
Panos Lorentziadis

We consider a procurement auction in which bidders employ local firms as representatives. Overseas companies seek this type of partnership to address requirements for local after-sales service, to enhance the promotion and marketing of the product portfolio and to overcome bureaucratic obstacles often found in public procurement. In many countries, such as Mexico, Japan, India foreign exporters are advised to co-operate with a local partner for government contracting while in other countries such as Brazil the appointment of a local representative is obligatory. The effort that a local agent devotes in a procurement project affects the probability of winning the auctioned contract. We investigate how firms should compensate local agents and at the same time determine the bidding price in order to maximize their expected profit. The compensation system acts as a motivation for the effort allocated by the local agent while at the same time the payment of commission leads to an increase of the total bidder cost. We compare the effect of different compensation plans embedding the auction into a multidimensional bidding environment. Further, we explore profit sharing among the auction partners and we provide a connection with agency theory. Finally, we discuss extensions of the environment that we examine.

■ MC-30

Monday, 12:30-14:00 - Virtual Room 30

System Dynamics Modeling and Simulation - Session 1

Stream: System Dynamics Modeling and Simulation
Invited session
Chair: *Markus Schwaninger*
Chair: *Matthias Otto Müller*

1 - Using input-output principles in a System Dynamics macroeconomic model
David Wheat

This paper presents a multi-industry regional model that combines input-output (IO) modeling principles within a system dynamics(SD) macroeconomic model. It is well known that input-output models have both strengths (internally consistent intermediate demand structure) and weaknesses (static technology and prices). Another weakness in most IO models is that final demand is exogenous. Our SD model includes price and technology dynamics and closes the feedback loop between the supply and demand sides of the model economy. The proof-of-concept example uses data from the Dontetsk and Luhansk regions of Ukraine. We also discuss the challenges of estimating technical coefficients for a regional input-output model when only national coefficient data are available, as well as some of the limitations of the current version of the SD model.

2 - Upgrading organic profit sharing and employment targeting in bi-dimensional Goodwinian models
Alexander Ryzhenkov

The paper reveals how the bi-dimensional non-linear Lordon - Goodwin model L-1 endogenously generates cycles of absolute and relative over-accumulation of capital parallel related to the observed industrial cycles. In L-1, a rise in unit value of labour power above a threshold calls forth crises and destruction of capital.

L-1 hyperbolizes the acuteness of accumulation crises. By correcting functional relations for wage terms, first, and for capital accumulation rate, second, the present paper transforms it into L-2. The model calibration has been improved. Scenario 1 is a futile attempt to achieve hastily a higher employment than the current level by stabilization policy based on mechanistic profit sharing in L-2.

The original equations for profit sharing and bargained wage terms are revised in L-3 where the growth rate of surplus value depends, firstly, positively on a gap between the target and current employment ratios and secondly, negatively on a growth rate of the employment ratio. The latter policy rule does not cause over-shooting of profit and undershooting of wage in satisfying scenario 2.

An analysis of local stability of stationary states for these non-linear models is extended by exposing transients to distant attractors. The system dynamics methods have helped in upgrading organic profit sharing. The research offers new insights on the tendency to secular stagnation that will serve a socially efficient recovery from the international crisis.

3 - Structural analysis of System Dynamics models
Lukas Schoenenberger, Alexander Schmid, Radu Tanase, Mathias Beck, Markus Schwaninger

System dynamics (SD) is an established discipline to model and simulate complex dynamic systems. The primary goal of SD is to evaluate and design new policies that can impact the system under study in a desired way. Policy design, that is, identifying effective model levers, however, is a challenge and in many cases trial-and-error driven. In this article, we introduce a new and coherent framework for model analysis, called structural analysis methods (SAM), to facilitate the policy design process in complex SD models. SAM provides a resource-efficient and effective means for the detection of candidate policy parameters. It enables to identify intended and unintended effects of activating these policy parameters, and to discover candidate structural changes such as introducing new variables and links in SD models. The main innovation of SAM is that it translates the structure of SD models into weighted digraphs allowing algorithmic tools from the realms of graph theory and network science to be applied to SD. SAM is validated on the basis of two well-known simulation models of increasing complexity: the third-order Phosphorus Loops in Soil and Sediment (PLUM) model and the fifth-order World2 model. The validation shows that SAM seems to be most valuable for the analysis of more complex simulation models (World2) and is less suited for the analysis of low complexity models (PLUM).

4 - Supporting System Dynamics modelling with a Python-based test automation toolbox
Matthias Otto Müller

System Dynamics modeling is highly iterative. Often, a model goes through hundreds or even thousands of iterations before modelers are satisfied that the model meets the purpose and is consistent with their knowledge of the system. For small models, it is straightforward to keep track of this in an ad-hoc manner. Yet, as models grow bigger, it becomes increasingly difficult to verify that the latest iteration does not have undesired consequences. Even in published and carefully reviewed models, problems like negative values in physical stocks, high-speed oscillations, or a poor fit of model behavior with time-series data can be found. The root cause of this problem is that modelers don't have the time or the diligence to inspect each variable with the rigor that is required. How might such limitations of human cognition be overcome? In the realm of software development, this problem has been mitigated by the use of test automation. Test scripts run the software under evaluation with pre-defined inputs and check whether it produces the expected outputs. If the software fails to produce the expected output, then this indicates a flaw that requires manual inspection. The same approach can be used for automating the testing of System Dynamics simulation models. Specifically, this presentation will show a test automation toolbox implemented in the Python programming language that supports modelers in quickly finding problematic aspects of their model.

■ MC-31

Monday, 12:30-14:00 - Virtual Room 31

Applications and Methods of Multiobjective Optimization

Stream: Multiobjective Optimization
Invited session
Chair: *Joshua Knowles*

1 - Matrix-dominance, a new multi-objective concept used in real time rescheduling in dense railay systems
Hugo Belhomme, Stéphane Dauzere-Peres

Rescheduling trains in a dense railway system and in real time can be a challenging multi-objective optimization problem, where criteria such as train delays and passengers impact should be minimized. The notion of Pareto dominance allows to compare solutions on multiple objectives at once, and it is the heart of multi-objective optimization. This presentation introduces matrix-dominance, a concept extending Pareto dominance and takes into account industrial knowledge. This new notion of dominance allows to finely model the tradeoffs between some decisions which are to avoid and their impact on objectives and it guarantees the quality of solutions presented to the decision maker. After presenting our industrial context dealing with commuting trains in Paris, we introduce our problem and the solution method which has been integrated into a decision support tool. We then discuss the academical and industrial interests in developing a new type of dominance. Finally, we introduce the notion of matrix-dominance, based on required payoff matrices, we discuss the challenges of this new concept and we present some preliminary results.

2 - Cutting Planes for Robust Biobjective Optimization
Fabian Chlumsky-Harttmann, Marie Schmidt, Anita Schöbel

In recent years several optimality concepts for robust multi-objective optimization have been introduced. However, not many approaches to actually solve such problems have been proposed. In our work, we consider uncertain linear biobjective optimization problems and attempt to find point-based minmax robust efficient solutions, i.e., solutions that are efficient in their objective-wise worst case. To this end, we build on two well-known procedures: Dichotomic search, which uses weighted-sum scalarizations to determine the Pareto front of (deterministic) linear biobjective problems, and a cutting plane approach, that incrementally increases the set of considered scenarios and originates in robust (single-objective) optimization. Our proposed algorithm combines both methods and increases the uncertainty set while moving along the Pareto front, thereby solving problems that are both uncertain and biobjective. We prove its correctness, study its performance and demonstrate its benefits.

3 - A Multiparametric Programming Approach for the Multiobjective Optimization of Mixed-Integer Linear Programs
Iosif Pappas, Styliani Avraamidou, Justin Katz, Baris Burnak, Burcu Beykal, Metin Türkay, Efstratios Pistikopoulos

Practical applications of optimization for process systems involve the simultaneous satisfaction of often conflicting financial, safety and environmental targets. A way to address that is through multiobjective optimization whose result is a set of trade-off solutions that meet all those criteria. The multiobjective optimization of mixed-integer linear formulations is of particular importance, especially when considering the design and operation of a given system. Proposed methods to solve such problems include enumerating schemes, the ϵ-constraint method, branch & bound, PolySCIP and the GoNDEF algorithms. However, many of these algorithms rely on generating grid points, require the solution of subproblems to map the Pareto front, or refer to bi and tri-objective problems.

In this work, we present a framework for the exact explicit derivation of the Pareto front of multiobjective mixed-integer linear optimization problems through multiparametric programming. We utilize the ϵ-constraint approach to reformulate the original formulation to a multiparametric mixed-integer linear programming problem where the ϵ scalarization parameters are treated as right-hand side uncertainty. Subsequently, the algorithm calculates the optimal trade-off solutions as explicit affine functions of the ϵ parameters. A computational study is used to evaluate the computational performance of the approach, while its applicability is demonstrated through an engineering case study.

■ MC-32

Monday, 12:30-14:00 - Virtual Room 32

Fair and explainable models 1

Stream: Multiple Criteria Decision Analysis
Invited session
Chair: *Miguel Couceiro*
Chair: *Luis Galarraga*

1 - What is fair data manipulation?
Alexis Tsoukias, Claire Barale

Decision making is essentially a data driven (or evidence based) activity. However, decision makers rarely use raw data, as these are collected from empirical observations. Most automatic devices manipulate raw data aiming at providing insight to human decision makers involved in different types of decision processes. However, very often the procedures which manipulate data, conceal assumptions, biases and drawbacks to which the users are unaware, leading to counter-intuitive decisions, misunderstandings and to controversies, not to mention explicit or implicit discrimination. The paper aims at exploring this vast field, contributing to the establishment of a framework defining which data manipulations are admissible and for which purpose. Among the many topics which may characterise admissibility we will focus to fairness of data manipulation.

2 - A model-agnostic approach to reducing Bias in textual classifiers
Miguel Couceiro

The recent advances in artificial intelligence and machine learning (ML), and in particular deep learning, have made algorithmic decisions and predictions ubiquitous. This includes applications that have a direct impact in people's lives, e.g., loan grants, terrorism detection, identification of hatred and fake news, and even prediction of criminal recidivism. Such reliance on machine support naturally raised several transparency and fairness concerns about these, many times opaque, ML processes. These concerns were in part rooted in recent studies that revealed unacceptable biases in such ML processes. Those biases can lead to discriminatory and unfair decisions. In this talk we address the problem of detecting and tackling biases in ML textual classifiers. We will survey the state of the art approaches to textual classification, and present a system-agnostic solution that may not only detect biases in text classifiers, but also propose fairer classifiers without retraining them.

■ MC-33

Monday, 12:30-14:00 - Virtual Room 33

Multi-objective optimization sustainability-focused

Stream: Multiple Criteria Decision Analysis
Invited session
Chair: *Ana Garcia-Bernabeu*

1 - Incorporating sustainability considerations into the portfolio selection process using evolutionary multiobjective optimization
Ana Garcia-Bernabeu, Fernando Mayor-Vitoria, Marisa Vercher, Adolfo Hilario-Caballero

Markowitz conceived the idea of establishing the Paretian Efficient frontiers to portfolio selection in the framework of mean-variance (MV) optimization. Over the years, new research lines have been developed in the field of multi-objective tools to extend the classical mean-variance model by integrating additional criteria, such as liquidity, cardinality, and in recent years, sustainability. Within the multi-objective approaches to extend the M-V model, most of the contributions include the sustainability criteria under the consideration of additional constraint.

This research reviews recent initiatives incorporating environmental, social and governance (ESG) criteria in the portfolio selection process using evolutionary multi-objective optimization approaches. Besides, we address how sustainability is introduced as a third criterion through the evolutionary algorithm ev-MOGA, based on the concept of ϵ-dominance. The proposed ev-MOGA algorithm adjusts the Pareto front dynamically, ensuring convergence and uniform distribution of solutions. We also propose a new visualisation tool to understand better the trade-off between the three objectives giving a two-dimension representation of high dimensional Pareto fronts.

2 - Investing in the low-carbon transition: a multi-objective portfolio selection approach
David Pla-Santamaria, Marisa Vercher, Fernando Mayor Vitoria, Francisco Salas-Molina

Efforts to reduce the carbon footprint of equity portfolios is a growing trend in sustainable investing. Fund managers are turning their attention to the fight against climate change and are proposing strategies to decarbonise portfolios. The current trend is mainly based on the exclusion of companies with high CO2 emissions. However, the integration of carbon risk into portfolio selection criteria has not been considered so far. As a first step, rating agencies have started to develop indices that report on companies' commitment to reducing their carbon footprint. To help investors address this challenge, we propose a multi-objective evolutionary approach (MOEA) in which carbon risk is included as an additional objective. The suggested algorithm's performance is then tested on a cross-section of open-ended European socially responsible investment funds to assess the extent to which climate-related risk could be incorporated into the portfolio according to investor preferences.

3 - Portfolio optimization integrating sustainability by improved ev-MOGA
Adolfo Hilario, José Vicente Salcedo, Ana Garcia-Bernabeu, David Pla-Santamaria

The increasing complexity of financial decision-making, such as portfolio selection problems, has led researchers to apply heuristic procedures inspired by biological processes such as multi-objective evolutionary algorithms (MOEAs). These techniques provide satisfactory approximations of the efficient frontier even when the problem involves non-convexity, discontinuity or non-integer variables.

In this study, a new approach using a new multi-objective optimization evolutionary algorithm known as ev-MOGA is presented for placing the portfolio optimization problem, including sustainability as a third objective. The improvement includes the introduction of cardinality constraints and discretization of solutions in the parameter space. Based on the proposed allocation solutions, we also propose an a-posteriori approach to incorporate the investor's preferences into the decision making process. With this tool, the investors could address more effectively tri-criterion problems to easily visualize and find a desirable trade-off among conflicting objectives. Finally, the performance comparison of ev-MOGA and the improved ev-MOGA is carried out using a sample of socially responsible mutual funds offered in Spain.

■ MC-34

Monday, 12:30-14:00 - Virtual Room 34

CO problems in maritime and intermodal logistics

Stream: Combinatorial Optimization
Invited session
Chair: *Anna Sciomachen*

1 - Optimization Approaches to define Storage Strategies for the export yard in container terminals
Haoqi Xie, Daniela Ambrosino, Anna Sciomachen

Maritime container terminals play a crucial role as intermodal change nodes in the logistic chains. Recently, the main focuses seem to be transferred from quayside to yard side. This change elicits the discussion on improving the efficiency of typical operations performed in the yard, such as the storage, the retrieval of containers, and routing of handling equipment. In this work we propose a 0/1 linear programming formulation for defining storage rules able to minimize the space used in the export yard. Handling operations are executed thanks to reach stackers. Given an export yard organized in blocks of different capacities (i.e. the yard template is given), and known the subset of blocks dedicated to each vessel, the problem consists in determining the best storage consignment strategy to minimize the space used in the export yard. The aim is to determine the best rules for defining which containers to get stored together while determining the loading cluster for each group of containers. Containers are characterized by their type, size, weight and destination. The ideal rule is to store together containers having the same characteristics. According to preliminary tests, small-size instances can be solved up to optimality by using the proposed 0/1 linear programming formulation, a heuristic approach for solving large real instances is also suggested. A case study of an Italian terminal is presented and our solutions are compared with the real storage plans.

2 - Drone-based RFID monitoring in container ports.
Davide Donato Russo, Carmine Cerrone, Bruce Golden

Given a port with containers equipped with RFID tags, we investigate the usability of drones for tracking and locating containers. In particular, we focus on the definition of routes capable of minimizing the path followed by the drone in the monitoring phase. The operational scenario provides that each container is equipped with an RFID tag that can be identified by an antenna placed on a drone within a certain distance depending on the type of tag used. For each container, the starting position and the radius within which the tag can be identified is known. The starting position of the drone is also known. This problem can be modeled using the Close Enough Traveling Salesman Problem CETSP, if we add further restrictions to the computed route. In particular, the drone cannot move freely in the port area, it will have to avoid some forbidden areas, follow specific paths in some areas, while it will be able to move freely in other areas. In this work we will focus on this CETSP variant by formalizing the problem and designing a heuristic approach based on a problem discretization algorithm.

3 - Design of a Multi-Modal Transit integrating Dial-A-Ride and Fixed Routes

Nisrine Mouhrim, Andrea Araldo, Dominique Feillet, Yves Molenbruch, Kris Braekers

Fixed-Route Public Transport (FRPT) is critical for the mobility of urban conurbations. However, it is inherently unsuitable for suburban areas, where the demand density is low and, due to cost constraints, the service has a low frequency and limited coverage. This results in poor Quality of Service (QoS). On the other hand, the Dial-A-Ride (DAR), e.g., Uber,.., services have emerged but, due to their low capacity, they are unsuitable for high-density areas, where they would exacerbate congestion. While DAR operations and FRPT design have mostly been studied separately, the goal of this research is to develop a methodology for the design of "Multi-Modal Transit" (MMT). MMT integrates both FRPT and DAR, to improve QoS in particular in suburban areas, without substantially increasing the operational cost. We formulate the design of MMT as a bilevel problem. In the upper level, we decide on the FRPT lines and their frequencies, as well as the fleet size to allocate to FRPT and DAR. We do so using a Binary Particle Swarm Optimization (BPSO) metaheuristic. The lower level consists of an Integrated Dial-A-Ride problem (IDARP) to construct the multi-modal trips of customers (including FRPT and DAR legs) and the routes of the DAR vehicles, using a Large Neighborhood Search (LNS) metaheuristic. Results show that MMT improves passenger mobility over current urban transportation, in particular in suburban areas, without substantially increasing the operational cost.

4 - Strong cuts from compatibility relations for the Dial-a-Ride Problem

Sunil Morapitiye, Tamas Kis

In the Dial-a-Ride Problem, which is a variant of the well-studied Vehicle Routing Problem, a fleet of vehicles has to satisfy a set of transportation requests between given pickup and delivery locations, and the solution is a set of routes satisfying several constraints, and minimizing the transportation costs. Several classes of valid inequalities can be obtained from the compatibility relation on the arcs. These compatibility relations are derived from the constraints of the problem, such as precedence relations, time windows and the capacity of the vehicles, and their main use is to exclude infeasible vehicle paths. We present some of these known constraints and our contributions: a strengthened lifting for an existing class of cuts, a new family of valid inequalities, and a new exact separation algorithm for all these cuts. We also present some theoretical results: establishing connection between these cuts, and the edge-polytope of a bipartite graph which is used for separation, giving new insight into the strength of known classes of inequalities as well. Finally, we demonstrate the effect of adding the new cuts and using the new separation algorithm on benchmark instances from the literature.

■ MC-35

Monday, 12:30-14:00 - Virtual Room 35

Scheduling Topics in Modern Manufacturing

Stream: Combinatorial Optimization
Invited session
Chair: *Erwin Pesch*
Chair: *Alena Otto*
Chair: *Roland Braune*

1 - Integrated process and production planning for air bending

Alberto Tomas García, Dirk Cattrysse, Joost R. Duflou

Sheet metal workshops usually deal with high-mix, low-volume production. In this scenario, frequent tool changes are required at the bending stage. Finding the tool setup that allows collision-free production of a part through air bending with minimum number of tool stations and tool segments is an NP-Hard problem. Besides geometrical considerations, current setup planning algorithms aim to minimize the effort required to set up the machine layout of a given job, assuming that the press brake does not have any tools already in place. However, when considering the full production schedule, this approach leads to increased setup time since the possibility of reusing some of the tool segments of a previous job to set up the machine layout of the current job is neglected. Nevertheless, the extent to which one job can reuse the tool segments of its previous job strongly depends on the order of the jobs in the production schedule, which can be understood as a TSP problem, and the calculated machine layouts for each job, which is an NP-Hard problem. Several heuristics and metaheuristics that efficiently integrate the previous interrelated complex problems have been developed and evaluated. It is concluded that a modified nearest neighbour heuristic, coupled with a mixed-integer programming model for single job machine layout generation, delivers high-quality results with the lowest computational time compared to other considered algorithms.

2 - The integrated multi-site additive manufacturing batching and scheduling problem

Dominik Zehetner, Margaretha Gansterer

Additive Manufacturing is a technology with increasing relevance. It allows new ways of designing mechanical parts in a sense that they perform better in the technological point of view as well as in a supply chain perspective. Moreover, the flexibility of the technology may enable collaborative planning in manufacturing. However, collaborative planning has not been sufficiently studied in the context of additive manufacturing. The aim of our study is to close this research gap by demonstrating the impact of collaborative planning in the field of additive manufacturing. First, we introduce the multi-site additive manufacturing problem, where we assume that production orders have to be batched and scheduled at several geographically distributed manufacturing sites by a central authority. For this problem, we develop an efficient solution approach, where both the batching and the scheduling problem are taken into account. The model is solved by a hybrid MILP and Genetic-Algorithms approach, where subproblems are solved sequentially. In an extensive computational study, we show that cross-site production planning can decrease the overall costs of additive manufacturing operations significantly.

3 - Machine learning-based algorithm selection for a scheduling problem with unit-time parallel tasks

Roland Braune

This contribution is based on a multiprocessor scheduling problem with unit time parallel tasks and precedence constraints associated with minimum and maximum time lags. The objective is to minimize the total weighted completion time, where the weight of a task is equal to its size (width). This kind of objective function leads to a resource allocation profile that is "left-shifted" and hence avoids idle time to occur in earlier time periods. In the extreme case, the multiprocessor resource is maximally occupied in all time periods except for the last one, where just some residual load remains. This kind of allocation profile is referred to as an "ideal" schedule.

The goal is to predict the existence of an ideal schedule for a given problem instance and, consequently, to choose the appropriate algorithm for exact optimization. An instance that actually has a feasible solution in the form of an ideal schedule could be solved by generating maximal feasible sets of tasks only. Otherwise, a conventional branch-and-bound algorithm has to be used which also enumerates incomplete feasible sets, leading to a higher degree of combinatorics. Promising features are identified based on the problem definition, extracted and used for training various different binary classifiers known from machine learning. First computational experiments show prediction accuracies of around 90% and considerable time savings compared to exact optimization without algorithm selection.

4 - Anticipating complex nesting solutions in hierarchical production planning using machine learning models
Aykut Uzunoglu, Christian Gahm, Stefan Wahl, Axel Tuma

In hierarchical production planning, the consideration of interdependencies between superior top-level decisions and subordinate base-level decisions is essential. In this respect, the anticipation of base-level reactions is highly recommended. We analyze an application case originating from the metal processing industry. In this example, a serial-batch scheduling problem constitutes the top-level problem and a complex nesting problem constitutes the base-level problem. The top-level scheduling decision includes a batching decision, i.e., the determination of a set of small items to be cut out of a large slide. To evaluate the feasibility of a batch, the base-level nesting problem must be solved. Because solving nesting problems is time-consuming even when applying heuristics, it is troublesome to solve it multiple times during solving the top-level scheduling problem. For this reason, we propose an approximative anticipation of base-level reactions by machine learning to approximate batch feasibility and present a prediction framework to identify the most promising machine learning method for the prediction task. For training, validation, and testing, we develop a new instance generation procedure that uses a set of 6,000 convex, concave, and complex shapes to generate 88,200 nesting instances. Depending on further assumptions, we can report that the approximative anticipation leads to an appropriate batch feasibility decision for 98.8% of the nesting instances.

■ MC-36

Monday, 12:30-14:00 - Virtual Room 36

EEPA 1

Stream: EURO Excellence in Practice Award
Award Competition session
Chair: *John Poppelaars*

1 - NHSquicker: Shaping Demand for Urgent Care through Real-Time Data and Digital Nudges
Navonil Mustafee, John Powell

Our work aims to investigate if indirect suggestions (nudges) can support patients in need of urgent care to make more informed decisions about available healthcare choices. Our nudge is digital in nature and is delivered through the NHSquicker app. The app informs patients of alternative facilities for care that are located at a catchment-level (e.g., hospitals with A & E departments, urgent care centres [UCC] and minor injury units [MIU] that are part of the urgent care network). By combining the current wait time with travel time, the app directs users towards facilities where they may be seen quicker, so that patients can choose the appropriate type of treatment facility for their condition. Thus, beneficially, only those with more serious needs present at the A & E, thereby reducing overall demand on the A & E facilities by redirecting less serious cases to the more appropriate facilities of MIUs/UCCs. A & E waiting times are thereby reduced. It also helps to shape demand across the urgent care network by encouraging patients to choose an appropriate destination and optimal time of visit. NHSquicker is currently live in all of Devon and Cornwall and covers parts of Somerset and Bristol. It receives real-time data from 27 centres for urgent care, including nine emergency departments.

In this talk, we present the context and motivation for this work, the process of co-development of the solution with several NHS Trusts in the South West of England (as part of the Health and Care IMPACT Network), the data standard and the IT architecture, the initial rollout and deployment and the evidence of impact.

2 - Airport Staff Scheduling at Swissport International: 14 Years of Collaboration in Business Optimization
Andreas Klinkert, Peter Fusek, Bruno Riesen, Roman Berner

Swissport International Ltd. is the largest ground handling company worldwide, providing services for 82 million passengers and 4.1 million tons of cargo a year, with a workforce of 45,000 personnel at 269 airports. Swissport employs at its main airports up to 2500 people with hundreds of different work skills and shift duties, and a multitude of contract types. Monthly staff planning is highly complex and expensive, and usually requires extensive manual work by specially trained planners.

In 2007, Swissport launched a strategic R&D collaboration with the Zurich University of Applied Sciences (ZHAW), Institute of Data Analysis and Process Design (IDP), with the aim of developing innovative software for solving its challenging staff rostering problems. Evaluation of the commercially available tools showed that no software was able to satisfactorily solve the complex large-scale planning problems at Swissport.

Staff scheduling and rostering involves a number of hierarchical subproblems including demand modeling, task generation, shift design, days-off scheduling, shift assignment and real-time dispatching. When solving highly constrained large-scale workforce planning problems it is usually not computationally practical to deal simultaneously with all these tasks. Real-world software solutions typically decompose the overall planning task into heuristically designed subproblems which then are tackled by a variety of suitable exact and heuristic methods.

This presentation focuses mainly on the central rostering phase, which is the most complex, expensive and sensitive planning task at Swissport. The enormous effort involved can be illustrated by the example of Zurich Airport, where the initial rostering process with 20 planners took around 400 working days per month.

During a long-term strategic collaboration, a high-performance software for automated staff scheduling has been developed, which is able to efficiently solve Swissport's complex rostering problems. The methodology comprises a broad range of optimization techniques including preprocessing, decomposition, projection, and relaxation approaches, mixed-integer programming models, infeasibility analysis, and various heuristic procedures. Developing 'good' MIP formulations to reduce solver computation times was one of the most challenging parts and required substantial insights from combinatorial optimization, polyhedral combinatorics, and graph theory. The project was several times close to failing due to intractable MIP models and could only be continued thanks to mathematical breakthroughs leading to powerful new MIP formulations.

The developed software is fully implemented and in operational use at all major airports in Switzerland, including more than 55 internal customers, and its roll-out is continuously being expanded to other stations. Bottom line benefits include faster and more robust planning processes, improved roster quality and fairness, and significant financial savings.

3 - Intelligent Truck Drayage Dispatching and Appointment Booking: A real-world application in the Port of Hamburg (Germany)
Stefan Voss, Eduardo Lalla-Ruiz, Leonard Heilig

Container transportation is inseparable from container trucking, especially concerning the first and last mile. Truck drayage operations facilitate inter-terminal transportation within ports and transfers to hinterland connections (e.g., rail, barge). With growing problems related to limited capacities, traffic, peak demands, many restrictions and environmental requirements, manual dispatching of a large fleet of trucks reaches its limits. This impulsed the collaboration with EUROGATE, Europe's leading shipping line-independent container terminal operator, to extend their dispatching system with a modern cloud-based data-driven decision support system.

For addressing the challenge of making truck drayage operations more reliable and eco-efficient, we developed port-IO, a cloud-based platform combining modern digital technologies with operations research methods. It enables efficient coordination and management of container transports in real-time. This involved, on the one hand, the development of several (meta-)heuristics supporting the functionality of fast decision making as well as multi-objective approaches enabling simultaneous evaluation and analysis of economic and environmental objectives. On the other hand, this required the incorporation and utilization of operational analytics using machine learning approaches and data visualization techniques. Applying those methods into practice resulted in a 10-20% improvement regarding transport distances and fuel consumption and a 15% reduction of empty trips, besides a fair distribution of orders to truckers, which was improved by 50%. In a follow-up project, we further satisfied requirements for chassis equipment swaps and incorporated automated slot booking into the optimization to fit plans with slot availabilities from the mandatory truck appointment system (TAS).

The successful application gained huge interest in the industry and by a major stakeholder, paving the way for a new start-up, driveMybox. driveMybox is the first digital all-in-one platform that fully supports processes from the booking in a modern cloud-based platform to the execution using a trucker app, with optimization and machine learning approaches at its core and full transparency for customers. During the beta phase and since the official go-live in August 2020, the platform has handled more than 10.000 bookings in Germany and beyond and plans a turnover in the seven-digit range in 2021. The international expansion is planned for starting this year.

■ MC-38

Monday, 12:30-14:00 - Virtual Room 38

Emergency Services

Stream: ORAHS: OR in Health and Healthcare
Invited session
Chair: *Melanie Reuter-Oppermann*

1 - Data-driven forecasting for operational planning of emergency medical services

Paulo Abreu, Inês Marques, Ana Paula Barbosa-Póvoa, Daniel Santos

Emergency Medical Services (EMS) are a vital component of pre-hospital medical care, playing an important role in preserving human lives. The pressure on these services is increasing, as planners need to deal with conflicting objectives, such as demand coverage, costs, and population equity to allocate scarce resources, i.e. staff and emergency vehicles, to meet the growing demand. To tackle this problem, a data-driven forecasting method is proposed to predict volumes of EMS calls and dispatches of emergency vehicles since demand forecasts are important inputs to support resource allocation decisions. The method is based on data-mining tasks to build spatio-temporal datasets with multiple cross-attributes that help to explain demand patterns of a given region, in addition to addressing the problem of demand shared by neighboring zones. This method was tested using the case study of the Portuguese EMS, developing neural network (NN) models to predict the volume of calls and dispatches of vehicles using the regression concept, while calls are additionally explored using classification. Good results were observed in terms of model accuracy, as well as the flexibility of the method, which encourages the application of the method for other emergency medical systems. Additionally, the NN models developed using the proposed method are practical for planers, since the same model can be used for an entire year, and can contribute to real-time decision-making.

2 - The multiple ambulance type dispatching and relocation problem: the Portuguese case

Ana Sofia Carvalho, Maria Eugénia Captivo

The ambulance dispatching and relocation are two of the most studied problems in the Emergency Medical Service (EMS) context. Dispatching decisions assign ambulances to emergencies, and the relocation problem decides to which base ambulances should be (re)assigned. Different ambulance types, which vary in the equipment and crews, should be used according to the emergency severity. Having the Portuguese EMS as a case study, several real-life features are considered, such as extra time above the maximum response time, the setup time to crews to get ready, and ambulances' working shifts. We propose a new preparedness measure to achieve a good service level for current and future emergencies, considering different ambulance types. The proposed strategy considers the preparedness measure and allows relocations to any base. A mathematical model and a pilot-method heuristic are developed to solve these problems. To help the EMS managers in the decision-making process, we use a Geographic Information System (GIS) to develop a GIS-based tool. The proposed strategy and the current Portuguese EMS strategy, which dispatches the closest available ambulance and relocates ambulances to their home bases, are embedded in this tool. Running simulations for all day, we highlight the proposed strategy's potential.

3 - Investigating strategic factors that affect waiting times in an emergency department

Alessandro Nonis, Ernst-Jan Camiel Wit, Clelia Di Serio

Waiting times in accident and emergency (A&E) depend on a number of factors. The aim of the work is to identify the most important factors that affect patients' waiting times in order to determine whether the A&E system functions appropriately. We study the arrival times in a major hospital in Milan (Italy) during 2018. We find that waiting times depend mainly on severity of the patient at arrival (color code): severe patients are immediately treated and urgent patients have a short waiting time while patients with a non-critical condition can wait even several hours before being visited. Importantly, there is only marginal fluctuations across the day, suggesting that the system is able to deal quite effectively with the large fluxes in the arrival process across the day. Clearly, queue size and crowding of the ER affect the waiting times. Also, different departments of the hospital behave differently in terms of waiting times: bigger departments like medicine and surgery are quite comparable, while smaller departments such as Gynecology and Ophthalmology tend to be faster than the others. However, there remain significant differences in waiting times between the various days of the week, with Monday being particularly busy and Thursday less so. Also, surprisingly, we find that men, even accounting for the other factors, seem to be treated slightly faster than women and arriving at the hospital by ambulance seems to slightly increase the waiting time.

4 - Patient Direction to Emergency Service Centers Minimizing Travel and Service Times

Burak Pac

We consider the dynamic hourly patient direction policies from districts to emergency service centers in a weekly planning horizon. Travel times to the assigned emergency service and total time in the service are computed based on a simulation model. The model is calibrated using existing performance data for missing data on personnel schedules. Simulation-genetic algorithm hybrid serves to generate the pareto efficient frontier for biobjectively minimizing maximum emergency service busy time and average service time including travel. For the single of objective of minimal average travel and service time, computational results indicate significant reductions compared to undirected patient arrivals, and balanced busy times for emgergency centers accompany.

■ MC-39

Monday, 12:30-14:00 - Virtual Room 39

Routing under consideration of human factors

Stream: Routing, Logistics, Location and Freight Transportation
Invited session
Chair: *Yue Su*

1 - Robust Workload Balance in Postal Delivery Services
Oscar Téllez, Véronique François, Yasemin Arda

Postal delivery services are an essential part of our lives. We use them whether to send Christmas cards or to receive everyday products directly to our doorstep. This service is assured by couriers who perform daily rounds in fixed geographic areas called districts. Districts are typically defined for a long period of time based on the expected demand. However, normal demand variation can negatively impact the couriers' workload, either by exceeding their shift duration, or by creating a largely unfair workload distribution among couriers on certain days. We address the problem of designing robust districts so that the workload of couriers remains balanced under stochastic demand and service times. The problem is modeled and solved as a two-stage stochastic program: the districting decisions are made in the first stage, and the robust workload balanced is estimated in the second stage. In order to include realistic distribution network features, the underlying problem is treated as a node, edge, and arc routing problem with stochastic customers and service times. This research is carried out in collaboration with bpost, the Belgian postal service company.

2 - The Dial-a-Ride Problem with Transfers and Walking
Idan Meshulami, Mor Kaspi

In this work, we define and study a new variant of the Dial-a-Ride Problem (DARP) which considers both transfers and walking, namely, the DARP with Transfers and Walking (DARPTW). In particular, passenger itineraries may include multiple transfers and multiple walking segments. The goal of the DARPTW is to minimize a multi-objective function consisting of the total distance covered by the vehicles, the number of transfers, the total walking distance and the total excess time of the passengers. Introducing transfers and walking presents several opportunities. Multiple transfers may allow balancing the vehicle loads and reducing the service area covered by each vehicle. Walking may assist in reducing unnecessary vehicle detours to remote locations and may facilitate significant shortcuts that the vehicles cannot perform due to travel directions imposed by the road network. Nevertheless, these extensions further generalize and complicate the DARP which is known to be NP-hard. We devise an efficient algorithm for the scheduling sub-problem and use it as a subroutine within Large Neighborhood Search framework. The algorithm determines the feasibility of given routing plans and applies fast scheduling heuristics. Numerical experiments are conducted using real-world data obtained from Bubble-Dan in Tel Aviv. Preliminary tests over thousands of scheduling sub-problem instances demonstrate that the scheduling heuristic finds the optimal schedule in more than 90% of the cases.

3 - Vehicle Routing and Scheduling for Private Hire Coach Industry
Seyed Mohammad Ghoreyshi, Antonio Martinez Sykora, Chris Potts

Private hire coaches are used by groups of people who wish to be taken together to a special event and then return, or who want to make a tour by visiting places of interest such as museums, historical buildings, etc. Planners working in the private hire sector are faced with the problem of assigning tasks and drivers to vehicles. Associated with each task is a start time and location, an end time and location, and an itinerary that must be followed. Some tasks require a coach and driver for the complete working day, while other shorter tasks can be combined to form a work package for a driver. For a work package to be feasible, it must be possible for the coach to travel between the end of one task to the start of the next task so that the coach is available at the required start time. Also, the coach to be used must have sufficient capacity for all tasks in the work package and must also have the necessary facilities required by each of the tasks. A further constraint is that the work package should allow the driver to take sufficient breaks to conform to EU rules. Various algorithms are proposed for creating work packages that contain all the tasks with the objectives of minimising the number of work packages and of the distance travelled. Computational testing with large real-world instances shows that these algorithms create better work packages than those used by the company that funded this research.

4 - A Deterministic Annealing Local Search for the Electric Autonomous Dial-a-Ride Problem
Yue Su, Jakob Puchinger, Nicolas Dupin

This paper investigates the Electric Autonomous Dial-a-Ride Problem (E-ADARP), which consists of scheduling electric autonomous vehicles (EAVs) to transport users from specific origins to specific destinations within predefined time windows. We propose a Deterministic Annealing (DA) meta-heuristic where efficient local search operators are integrated to enhance the solution's quality. The potential visits to the recharging stations are explicitly handled by a bi-directional insertion algorithm. Computational experiments prove the effectiveness of the proposed algorithm in solving E-ADARP. The experiments are conducted under three scenarios: low, medium, and high energy level restriction, representing the constraint on the minimum level of the battery capacity at the end of the route. For each scenario, adapted instances from the literature are tested, and an average gap of 0.58% is achieved compared to the best-known solutions for E-ADARP. Several new best solutions are found on previously solved and unsolved instances. Then, we investigate the effect of allowing multiple visits to the recharging stations. The experiments show that this operation can efficiently decrease the total cost and improve the solution feasibility. Furthermore, we establish new benchmark instances based on literature with up to 8 vehicles and 96 requests, with our algorithm providing feasible solutions that the exact method from the literature cannot solve in a given amount of time.

5 - Bi-Objective Special Education Needs Bus Routing Problem
Jacopo Pierotti, Lina Simeonova, Theresia van Essen

The School Bus Routing Problem is a combinatorial optimization problem whose aim is to route a fleet of buses at minimal cost. These buses must depart from the school, collect the students and return to the school while respecting the vehicles' capacity and time limitations. When considering students with special needs (e.g., autism), attenders (i.e., dedicated staff) must be routed as well for assistance purposes. In addition, we consider the familiarity level of the students inside a bus to ensure a pleasant quality of service. We define the familiarity level as an index expressing how well each student knows the other riders (fellow students and attenders) on the same bus. Doing so, we can enforce a necessary minimum level of familiarity to be attained by the solution. As often happens in vehicle routing problems, this raises an interesting trade-off between minimizing travel costs and maximizing the quality of the service. In this presentation, we introduce a MILP model to obtain the Pareto front for small instances and a metaheuristic to estimate the Pareto front for real-life instances. These real-life instances are based on data from a specialized school in the South-East of England.

■ MC-40

Monday, 12:30-14:00 - Virtual Room 40

Personnel scheduling in health care (1)

Stream: ORAHS: OR in Health and Healthcare
Invited session
Chair: *Jens Brunner*
Chair: *Sebastian Kraul*

1 - Exploiting tractable structures in personnel rostering
Chao Li, Pieter Smet, Patrick De Causmaecker

Although personnel rostering problems are typically NP-hard, particular tractable cases are identified in the literature. In this work, we focus on the joint structures among these polynomially solvable rostering problems. These problems are formulated as a unified linear program rather than network flow models to increase the generality. The further understanding of the tractable problems also helps solve NP-hard rostering problems, as the tractable structures could be found in their subproblems.

2 - Learning to Reduce State-Expanded Networks for Multi-Activity Shift Scheduling
Michael Römer, Till Porrmann

For personnel scheduling problems, mixed-integer linear programming formulations based on state-expanded networks in which nodes correspond to rule-related states often have very strong LP relaxations. A challenge of these formulations is that they typically give rise to large model instances. If one is willing to trade in optimality for computation time, a way to reduce the size of the model instances is to heuristically remove unpromising nodes and arcs from the state-expanded networks. In this talk, we propose to employ machine learning models for guiding the reduction of state-expanded networks for multi-activity shift scheduling problems. More specifically, we train a model that predicts the flow through a node from its state attributes, and based on this prediction, we decide whether to keep a node or not. In experiments with a well-known set of multi-activity shift scheduling instances, we show that our approach substantially reduces both the size of the model instances and their solution times while still obtaining optimal solutions for the vast majority of the instances. The results indicate that our approach is competitive with a state-of-the art Lagrangian-relaxation-based matheuristic for multi-activity shift scheduling problems.

3 - A Rolling Horizon Approach for Planning Chemotherapy Treatments and Oncologists Shifts in a shared outpatient cancer centre
Elena Tanfani, Giuliana Carello, Paolo Landa, Angela Testi

Due to the ever-increasing number of cancer patients, the demand for chemotherapy treatments has been rising in recent years. In the chemotherapy treatment process, each patient, after the blood test and before the drug infusion, must undergo an oncologist visit to decide if the patient's conditions are compatible with the treatment. As suggested by the Organisation of European Cancer Institutes (OECI), we consider a cancer centre where the main physical and human resources are shared among different specialties. Several optimization problems, at different decision levels, arise in managing and operating shared cancer centres. In this paper, we focus on jointly planning the weekly assignment of exam rooms and time slots to cancer pathologies and assigning visit blocks to the available clinicians over a monthly planning horizon. We consider different objectives, such as the amount of served demand and the clinicians' workload balance. We developed MIP models to build the weekly schedule and to provide a clinician's cover of the weekly schedule on a reference month. As we want to keep as much as possible the weekly schedule unchanged over a multi-month planning horizon, we propose a rolling horizon approach that determines a suitable clinician's assignment to the slots in the weekly schedule allowing a limited number of changes from one month to the next one. The models have been tested on real data from an Italian hospital.

4 - Effects of Training Priorities in Annual Scheduling of Medical Residents
Jens Brunner, Sebastian Kraul

Medical residents often have to pass through many departments, which place different requirements on them. They are informed about the upcoming departments by an annual schedule to keep the individual departments' service level as constant as possible. Due to poor planning and uncertain events, deviations in the schedule can occur. These deviations affect the service level in the departments as well as the satisfaction of the residents. This project analyzes the impact of priorities on residents' annual planning to overcome unknown departmental changes. We present a novel two-stage formulation that combines residents' tactical planning with daily and duty rostering's operational level. We determine an analytical bound for the problem that is significantly superior to the LP bound. Additionally, we approximate a bound based on the solution approach. In a computational study, we analyze the performance of various bounds, our solution approach, and the effects of additional priorities in residents' annual planning. It turns out that additional priorities can significantly reduce the number of unknown shifts to be worked. Finally, we derive a practical number of priorities from the results.

■ MC-41

Monday, 12:30-14:00 - Virtual Room 41

Rolling Stock and Vehicle (Re)scheduling

Stream: Timetabling and public transport
Invited session
Chair: *Rowan Hoogervorst*

1 - An Analytical Comparison of Models for Rolling Stock Scheduling
Rowan Hoogervorst, Boris Grimm, Stanley Schade, Ralf Borndörfer

A major step in the planning process of passenger railway operators is that of assigning rolling stock, i.e., train units, to the trips in the timetable. A rolling stock assignment should preferably satisfy the passenger demand, but also be attractive from the perspective of the railway operator. To support railway companies in scheduling their rolling stock, the literature has proposed a wide variety of models. These vary as a result of operational differences, and hence different requirements, between the considered railway companies. In this talk, we categorize the existing models according to these requirements and show the relations between them. Moreover, we make an analytical comparison between two models that have been proposed for the setting of Netherlands Railways (NS) and DB Fernverkehr AG (DB), respectively. Our analysis shows that these formulations lead to the same linear programming relaxation bound when considering the rolling stock scheduling setting of NS. Moreover, a numerical comparison shows that the model proposed for NS is able to find optimal solutions in shorter running times in this setting.

2 - A Simulation-Optimization Framework for Traffic Disturbance Recovery in Metro Systems
Marta Leonina Tessitore, Marcella Samà, Andrea D'Ariano, Dario Pacciarelli

Metro systems are used by millions of passengers every day. Maintaining a satisfactory quality of service is thus paramount but difficult, due to the high frequencies of services and probability of disturbances that may cause delays and disruptions. We create a simulation-optimization framework that analyses how delays propagate in a metro network when different recovery strategies are implemented. A traffic simulator, called SIMSTORS and based on a Stochastic Petri Nets variant, is used as surrogate for the real metro system. Following a closed-loop framework, where rescheduling measures are repeatedly computed on the basis of current traffic states and previous decisions, SIMSTORS rule-based algorithms have been integrated with the AGLibrary optimization solver, a deterministic solver for managing complex scheduling problems that formulates the real-time train rescheduling problem as an Alternative Graph. Several operational issues have been investigated throughout the use of this framework, among which how to design suitable periodic or event-based strategies, and how to decide the frequency and the length of the optimization process. The Santiago Metro Line 1, in Chile, is used as a practical case study. Computational results show that the best performance, in terms of train delay minimization and service regularity, can be achieved when using the optimization algorithms in addition to the rule-based embedded in SIMSTORS.

3 - The Electric Dial-a-Ride Problem on a Fixed Circuit
Yves Molenbruch, Ohad Eisenhandler, Mor Kaspi, Kris Braekers

Innovative shared mobility services involving electric autonomous shuttles have increasingly been implemented in recent years. Due to various restrictions, these services are currently offered on fixed circuits and operate on fixed schedules. This study introduces a service variant in which the shuttles' stopping patterns and schedules are determined in a flexible way. Specifically, in the Electric Dial-a-Ride Problem on a Fixed Circuit (eDARP-FC), a fleet of capacitated electric shuttles operates on a given circuit, consisting of a recharging depot and a sequence of stations where users can be picked up or dropped off. The shuttles may perform multiple laps between which they may need to recharge. The goal of the problem is to determine the vehicles' stopping sequences and schedules, including recharging plans, so as to minimize a weighted sum of the total user journey time and the total number of performed laps.

The eDARP-FC is formulated as a novel lap-based MILP and is shown to belong to the class of NP-Hard problems. Efficient polynomial time algorithms are devised for two special scheduling sub-problems. These algorithms and several faster heuristics are then applied as subroutines within a Cross-Entropy metaheuristic tailored to the eDARP-FC's structure. Experiments on instances derived from a real-life system demonstrate that the flexible service allows providers to reduce operational costs and improve service quality.

4 - Timetable-based railway network design
Tim Sander

In various european countries, including Switzerland, the Netherlands and Germany, the design of railway infrastructure networks is driven by timetables which determine the design and the extensions of railway networks. This paper presents an approach for the automatization of the timetable-based railway network design. Based on a macroscopic timetable with a set of trains and their properties, including source and destination nodes as well as bounds for departure and arrival times, a cost-optimal set of arcs is constructed so that all trains can reach their destinations within the given time windows. The detailed routing and timing of the trains is determined during the optimization. The usage of minimal headway times depending on arc properties, train succession and train types ensures a realistic capacity estimation. For each arc, key properties such as train-type-dependant travel times, minimal headway times and the number of tracks per direction are determined by the model. In order to ensure performance for larger instances, both row and column generation approaches are implemented. The model is tested using data from the german „Deutschlandtakt". Further extensions will include the consideration of robustness of the resulting infrastructure measures against changes of the input timetable.

■ MC-42

Monday, 12:30-14:00 - Virtual Room 42

Scheduling problems in sustainable supply chains

Stream: Sustainable Supply Chains
Invited session
Chair: *Thomas Kirschstein*

1 - A hybrid metaheuristic for yard crane scheduling problem considering energy consumption
Ran Wang, Afshin Mansouri, Cihan Butun

In the past decade there has been a growing trend of studies focusing on the productivity of container terminals, but very few of them considered the environmental sustainability. In this paper, we tackle a bi-objective yard crane scheduling problem that aims to minimise the total tardiness of jobs and the total energy consumption of yard cranes. Two types of cranes are used for the container movements: rubber tyred gantry cranes (RTGs) and reach stackers (RSs), which are frequently used for jobs such as stacking, retrieving, and reshuffling of containers. RTGs generally operate in a single block whilst RSs can carry containers between blocks. There is usually a trade-off between productivity and energy-saving in yard crane scheduling problems. When cranes prioritise the minimisation of total job tardiness, the travel distance related energy consumption could increase. The problem is firstly converted into a vehicle routing problem with time windows and formulated as a mixed integer programming model. We propose a hybrid metaheuristic, which combines Pareto archived evolution strategy with a simulated annealing method as local search. We demonstrate the applicability of our approach using data of a container terminal in Spain. The results indicate the viability of our model and the solution method in providing insights to the yard operation planners in making informed decision considering trade-offs between performance- and sustainability-oriented key performance indicators.

2 - Sustainability considerations in container pre-marshalling problem
Cihan Butun, Afshin Mansouri, Ran Wang

Environmentally sustainable operations are vital for container terminals due to their prominent role in global supply chains and geographical proximity to urban areas. Although there is a growing scholarly interest in sustainable maritime logistics in parallel with the changing priorities of the industry, the analytical research in many areas of port operations still solely focuses on the productivity. In this paper, we address this gap and tackle a container pre-marshalling problem with sustainability considerations. The task in the problem is to determine the reordering move sequence of containers in a terminal yard bay to achieve an ordered bay configuration by minimizing the energy consumption of the yard cranes involved in pre-marshalling. We formulate the problem as a mixed integer linear programming model and present a solution method that utilizes A* algorithm. The proposed method treats feasible move sequences as paths originating from the initial bay configuration, ordered bay configurations as goals, and employs a novel heuristic function to estimate each path's remaining energy consumption and number of moves to reach a goal. The experiments performed with the use case scenarios provided by a Spanish container terminal confirm the effectiveness of the proposed solution method, demonstrate that energy savings can be achieved without disrupting the terminal productivity, and validate the consideration of sustainability in pre-marshalling operations.

3 - Energy demand of parcel delivery services with a mixed fleet of electric vehicles
Thomas Kirschstein

Drone logistics is considered as a disruptive business model reshaping logistics in the next decades. Most prominent potential advantages of drone delivery are cost savings, high speed, and high flexibility. Additionally, drones are also considered as a means of green transportation as they are electric vehicles which are potentially emission free. To which extent these potentials can be realized depends on environmental and technological conditions. In this study a stationary drone delivery system is considered where parcels are delivered from a central depot to customers either by drone or electric truck. The minimal total energy consumption for serving all customers is determined by solving a selective travelling salesman problem with an simple but effective heuristic. In a simulation study the effects of structural characteristics (like numbers of customers and customer density) and environmental conditions (like wind speed and traffic conditions) on potential energy savings using a mixed fleet are estimated. The results indicate that structural characteristics and environmental conditions heavily affect the energy saving potential of drones. In urban settings with high customer density, the energy saving potential is limited to about 1 % on average while in rural settings drones can help to save about 5 % of total energy. However, under drone-favoring conditions like calm winds and heavy traffic, the energy saving potential can double.

■ MC-43

Monday, 12:30-14:00 - Virtual Room 43

Stochastic models in hospital and appointment management

Stream: Stochastic Modeling in Health Care
Invited session
Chair: *Semih Yalçındağ*

1 - Stochastic Scheduling of Chemotherapy Appointments under the Consideration of Patient Acuity Levels
Sırma Karakaya, Serhat Gül, Melih Celik

Chemotherapy scheduling is a challenging problem due to uncertainty in infusion durations and non-homogeneous care level needs of patients. We study the problem of scheduling patient appointments and assigning patients to nurses under uncertainty in infusion durations for a given day. We consider instantaneous nurse workload, which is represented in terms of total patient acuity levels, and chair availability while scheduling patients. We formulate a two-stage stochastic mixed-integer programming model to represent the problem. We propose a scenario-bundling based decomposition algorithm to find near optimal schedules. We use data of a major university hospital to generate managerial insights related to chemotherapy scheduling.

2 - Modeling COVID-19 hospital admissions and occupancy in the Netherlands
Ger Koole, René Bekker, Michiel uit het Broek

We describe the models we built for hospital admissions and occupancy of COVID-19 patients in the Netherlands. These models were used to make short-term decisions about transfers of patients between regions and for long-term policy making. We motivate and describe the model we used for predicting admissions and how we used this to make predictions on occupancy.

3 - Designing master surgery schedules with downstream unit integration via stochastic optimization
Daniel Santos, Inês Marques

Surgical activity has a substantial impact in all areas of hospitals. Additionally, social concerns arise related to equity and speed of access. Therefore operating room management is paramount in the modern society. This work studies the master surgery scheduling problem which is the problem of assigning surgical specialties to operating room blocks, which represent a shift of an operating room. For a master surgery schedule to be applicable in practice, multiple considerations must be taken into account. The particular focus of this work is in the integration of downstream units, i.e., beds. Although in a tactical planning scenario operational bed requirements are unknown, these may be estimated based on historical data. We propose a stochastic optimization model that captures the uncertainty in the bed requirements, with a recourse function that reduces the overutilization of beds. A solution approach based on Benders decomposition is developed and results for instances generated based on real-life data are presented.

4 - MDP Model for the Preference-Based Appointment Scheduling Problem with Multi-priority Patients
Feray Tuncalp, E. Lerzan Ormeci

We consider the problem of appointment scheduling for a physician or a diagnostic resource in a healthcare facility. Patients contact the facility either through a call center where patients are scheduled immediately, or through a website which produces a list of patients to be scheduled every morning. Patients are further differentiated according to their priority classes, possibly depending on their insurance types. The facility aims to maximize the expected average revenue, while ensuring that a certain service level is satisfied for lower-priority patients. Different priority classes may have different preferences, which are represented through multinomial logit models. The facility has two types of decisions: offering a set of appointment days to a patient according to her priority class and choosing the patient class (from the patient list generated through the website) to contact with. We model this system as a Constrained Periodically Time-Inhomogeneous Markov Decision Process model. We derive analytical results on the structure of the optimal policy and implement a simulation-based booking limit improvement policy by approximating the value function to solve this model. In this manner, we combine simulation optimization with approximate dynamic programming (ADP) techniques to develop a good solution for the model. The performance of this policy is evaluated in a numerical study through a comparison with certain benchmark policies.

■ MC-44
Monday, 12:30-14:00 - Virtual Room 44

Machine learning and OR

Stream: Practice of OR (Making an Impact)
Invited session
Chair: *Sofiane Oussedik*

1 - Machine Learning and OR
Sofiane Oussedik

There is a lot of synergy and complementarity between Operations Research (OR) and Machine Learning (ML). While some ML experts use OR to improve the machine learning models, OR experts use ML more and more to incorporate learning in their optimization algorithms. The two technologies also complement each other to deliver more value to business users and higher impact. In this session we'll discuss some examples with a focus on real life problems.

For latest information on speakers and other details, visit the 'Making an Impact' webpages here: https://euro2021athens.com/specific-sessions/

■ MC-45
Monday, 12:30-14:00 - Virtual Room 45

Inventory and transportation planning

Stream: Production, Service and Supply Chain Management
Invited session
Chair: *Birger Raa*

1 - Exact solution procedures for the stochastic inventory transportation planning in maritime supply chains
Majid Yazdani, Tarik Aouam

This work studies the coordination of transportation planning and multi-echelon inventory optimization in a maritime supply chain facing uncertain demand of a single product. By adopting a guaranteed service approach, we formulate an integrated problem that jointly optimizes inventory targets and transportation-related decisions, including direct shipments from multiple-origin ports to multiple-destination ports, fleet sizing, and ship speed selection. The objective is to minimize the expected total inventory and transportation cost, while meeting specified service levels. Using structural properties of the optimal solution, alternative mixed-integer nonlinear formulations are presented and solved using exact solution procedures. Numerical experiments illustrate the importance of adopting multi-echelon inventory optimization for planning inventory in maritime supply chains and that there is great value in coordinating inventory and transportation planning decisions. Additionally, extensive computation experiments show that the proposed solution procedures find optimal or near-optimal solutions for reasonable supply chain sizes and outperform a state-of-the-art nonlinear commercial solver, in terms of solution quality and CPU times.

2 - Exploring the seller-buyer relationship in a two-stage supply chain with imperfect quality products
Zsuzsanna Hauck, Boualem Rabta, Gerald Reiner

We consider a two-stage supply chain with imperfect quality products where screening decisions affect the screening cost in addition to the quality of the final product. Obviously, screening parameters can also have an impact on consumer satisfaction, increase the returns due to quality complaints and result in penalty cost. We explore the seller-buyer relationship in this regards and investigate both cooperative and non-cooperative contracts via a mathematical model. In the non-cooperative scenarios, the buyer has power over the seller and can decide on the quality level and the order size. The seller bears screening costs while it differs in the sub-scenarios which party decides on the wholesale price. On the other hand, in the cooperative scenario, decisions are made jointly to maximize the integrated supply chain profit and we assume a fair sharing of the costs as well as the benefits. The problem is solved analytically, followed by numerical examples to investigate the impact of the corresponding decisions on the overall supply chain profit under various assumptions. Various contracts are considered and their impact on both parties is emphasized. Results include that not only the seller but also the buyer and the customers can benefit from an effective cooperation.

3 - Stochastic cyclic inventory routing with capacitated replenishments

Birger Raa, Tarik Aouam

The cyclic inventory routing problem (IRP) considers a set of retailers with stable demand rates being replenished from a central warehouse over an infinite horizon. The retailers are partitioned into subsets, each covered by a vehicle route that is periodically repeated. The route cycle times are chosen such that the costs of making the route are balanced with inventory-related costs at the retailers in the route. When the retailer demand rates are stochastic, safety stock is required and the cost trade-off is extended to include expected stockout costs. The amount of safety stock and the stockout risk depend on the route cycle time. Stochastic demand rates also result in variable replenishment quantities from one cycle to the next. There is thus a certain risk that the cumulative replenishment quantity of the retailers in a route exceeds the vehicle capacity. This risk also depends on the route cycle time. To cover this risk, additional measures are necessary. We consider two possibilities. Either an expedited shipment is initiated whenever the vehicle capacity is exceeded, or additional safety stock is kept at the retailers to make up for the replenishments that are slightly less than needed every now and then. We present local-search heuristics to design routes and optimize the cycle times for this cyclic IRP with stochastic demand rates and limited vehicle capacities. Computational results provide insights into the intricate trade-off between the various cost elements.

4 - Oxygen Supply Chain Planning during COVID-19 Pandemic

Yena Lee, Vassilis Charitopoulos, Karthik Thyagarajan, Ian Morris, Jose M. Pinto, Lazaros Papageorgiou

With the ongoing SARS-CoV-2 pandemic becoming increasingly widespread and oxygen-therapy being the current dominant treatment of patients, securing reliable operation of medical oxygen supply chains becomes increasingly urgent. Nonetheless, the critical issue of facilitating agile decision-making in the medical oxygen supply chain using frameworks based on mathematical programming has received no attention. In this work, we address the problem of planning for the UK oxygen supply chain comprising production facilities, intermediate storage locations, filling stations, distribution network, and distribution resources. For the demand side, we consider the entire oxygen demand throughout the UK to maintain the continuity of supply required by integrating COVID-19 related and general hospitals, and industrial users. Moreover, we incorporate multiple scenarios that reflect oxygen demand increase for COVID-19 affected areas so as to achieve enhanced customer service responsiveness at minimum supply cost. The overall problem is formulated as a multi-period mixed integer programming (MILP) model. The key decisions involve production levels of production plants, delivery timings and amounts through heterogeneous vehicles, and inventory strategies for national stock-out prevention. Finally, the applicability of the model is demonstrated by a real-world case study in the UK.

■ MC-46

Monday, 12:30-14:00 - Virtual Room 46

Stochastic Models I

Stream: Stochastic Models in Manufacturing and Services
Invited session
Chair: *George Liberopoulos*

1 - Electric Vehicle Charging Station Search: on the Benefits of Information Sharing in a Stochastic Multi-Agent Setting.

Marianne Guillet, Maximilian Schiffer

Range and charge anxiety remain essential barriers to a faster electric vehicle (EV) uptake. Finding suitable charging stations reliably and quickly may mitigate an EV driver's anxiety. To this end, existing commercial services help drivers find available stations based on real-time availability data but struggle with data inaccuracy, e.g., due to ICEing. In the literature, stochastic search methods account for availability uncertainty and minimize a driver's detour to reach an available station. So far, both approaches ignore user coordination enabled by data sharing, which can reduce station visit conflicts and improve the driver's charging experience. Against this background, we study coordinated stochastic search algorithms tailored to various information-sharing and decision-making scenarios of practical relevance. We model the multi-agent stochastic charging station search problem as a finite-horizon MDP and introduce an online solution framework applicable for static and dynamic policies. Our methodology utilizes a hierarchical implementation of a single-agent heuristic for decentralized decision making and a rollout algorithm for centralized decision making. We present extensive numerical studies and show that a decentralized setting with visit intentions sharing and a static policy significantly improves individual search times and success rate compared to an uncoordinated setting and shows comparable performances to a centralized setting with a dynamic policy.

2 - An Efficient Approach to Distributionally Robust Network Capacity Planning

Francis Garuba

In this paper, we consider a network capacity expansion problem in the context of telecommunication networks, where there is uncertainty associated with the expected traf- fic demand. We employ a distributionally robust stochastic optimization (DRSO) frame- work where the ambiguity set of the uncertain demand distribution is constructed using the moments information, the mean and variance. The resulting DRSO problem is formu- lated as a bilevel optimization problem. We develop an efficient solution algorithm for this problem by characterizing the resulting worst-case two-point distribution, which allows us to reformulate the original problem as a convex optimization problem. In computational experiments the performance of this approach is compared to that of the robust optimization approach with a discrete uncertainty set. The results show that so- lutions from the DRSO model outperform the robust optimization approach on highly risk- averse performance metrics, whereas the robust solution is better on the less risk-averse metric.

3 - Dynamic Service Capacity Sizing and Customer Selection when Customer Demands are Driven by Past Service

Michalis Deligiannis, George Liberopoulos

A firm F serves a set of customers C over time. In each period, F selects its service capacity (SeC), and each C demands service with a probability that depends on her state, which is satisfied (S) or unsatisfied (U), depending on whether her last demand was met or not. Then, F selects which Cs to serve. Those served (not served) become S (U). Those who did not demand service remain in their previous state. F incurs a cost per unit of SeC and receives a C-specific revenue from each C served. Its objective is to decide its SeC and customer selection (CuS) policy to maximize its long-run average profit. We show that the myopic CuS policy is revenue-greedy (RG) and the myopic SeC policy is newsvendor-type. If the SeC is one less than the number of Cs, the optimal CuS policy is a priority index (PI) policy Z where the PI of each C is increasing in her revenue rate r and the ratio of her demand probabilities in the S and U states, ρ. As the number of Cs increases, the PI tends to rρ. For two Cs, the optimal SeC is fixed, and the optimal CuS policy is Z. For more than two Cs, we numerically compare the performance of the optimal SeC policy under three Lagrangian-derived PI CuS policies: (i) The Whittle-index policy, which is equivalent to the RG policy, (ii) a value-added (VA) policy, where the PI for each C approximates the value added by selecting vs. not selecting this C, and (iii) a conditional VA policy, where the added value is zero if the SeC covers total demand.

■ MC-47

Monday, 12:30-14:00 - Virtual Room 47

Emerging Applications in Management Science II

Stream: Emerging Applications in Portfolio Selection and Management Science
Invited session
Chair: *Alejandro Gutierrez-Alcoba*

1 - Optimization of a Flexible Schedule for Public Transportation with autonomous vessels
Julio C. Góez, Mario Guajardo, Stein W. Wallace

In this talk we consider autonomous vessels for transporting people on the coastal area of a city. Typically, vessels are schedule with predefined arrival and departure times established by the management following some criteria or a model. We propose an approach aiming to enhance the system operation, moving from a full fixed schedule to a system that follows the demand. We propose an optimization model aiming to minimize the penalty assigned to the deviation from the targeted users' arrival times. One challenge is that including full flexibility on the schedule may lead to problems that are impractical due the time required to find a solution, hence, defeating the purpose of an approach that aims to follow demand. To overcome that challenge, we developed an optimization model that mixes typical patterns of passenger movements for some established boat routes, while reserving some of the system capacity to respond to the dynamics of the demand. While the system could be in principle implemented with manned boats, the uncertainty introduced by the demand response schedule may lead to confusion and errors by the crew, and also not be incompatible with labor agreements. For that reason, the use of autonomous vessels is key to respond more precisely to last minute changes to the stops schedule. We present illustrative examples to show that the schedules found with this approach are both practical and may lead to a more efficient and flexible use of the boats in peak hours.

2 - Optimizing vehicle routing for regional food distribution of small farmers
Christina Scharpenberg, Jutta Geldermann

The demand for regional products is increasing in Germany in recent years. Main advantages of purchasing food regional are freshness due to short travelling distances, strengthening the local economy and thus environmental friendliness. To keep transport distances as short as possible and to offer a broad variety of local products, supermarkets cooperate with small, regional producers. So far, however, this concept involves an increasing organizational and logistical effort due to a lack of standardization and due to special requirements of regional producers. This tends to higher costs of the logistics processes especially at a 'last mile' and a 'first mile'. Therefore, we investigated three different vehicle routing strategies for the regional food distribution: single farmers' drop shipping, single farmers' round trip and bundled farmers' round trip. These three strategies are examined and compared regarding their transport cost structure and transport emissions. Our goal is to minimize costs and emissions caused by the transport. The results show, inter alia, that both delivery costs and emissions can be reduced by an average of 75% when switching from drop shipment to bundled famers' tours.

3 - An inventory routing problem on electrified road networks
Alejandro Gutierrez-Alcoba, Roberto Rossi, Belen Martin Barragan

While Electric Vehicles (EVs) are emerging as the solution for decarbonising private transportation in the future, a viable charging solution is needed for its adoption by Heavy Goods Vehicles (HGVs). Electrifying the roads, providing electric power to EVs from the grid, could make electric HGVs viable, and it stands as a solution for decarbonising road freight transport that has been trialled in several countries. In this work, we present an inventory routing problem for a hybrid HGV travelling on an electrified road network. In our problem, the vehicle transiting the network is equipped with a small electric battery and an auxiliary combustion engine that can be used, producing higher emissions, when there is no battery left. When the vehicle transits an electrified road segment it is powered by the electric grid, while the battery can be charged. We estimate battery and fuel requirements using a physics model which considers environmental and vehicle parameters, such as speed and weight. Being the weight of the vehicle one of the main factors in energy requirements, we study the problem in a stochastic setting for the demand of the customers scattered across the network. Lost sales of exceeding demand over inventory are backordered. We present preliminary computational results based on real data.

4 - Optimizing a Multi Battery Usage System for a Telecommunications Company
Isaias Silva, Cédric Bentz, Mustapha Bouhtou, Matthieu Chardy, Safia Kedad-Sidhoum

The use of batteries as a backup in case of power outages is a common practice adopted by telecommunications companies that need to keep their services always active. Besides, those batteries can also be used for other purposes such as participating in the energy market in order to reduce the electricity bill, as long as the safety usage rules are respected. In this context, batteries can be used when the energy costs more and recharged when the energy costs less, which is known as the demand-response mechanism. Our focus in this work is to optimize the use of batteries installed for backup to participate in the demand-response mechanism, in order to reduce the total energy cost for the company. We formally state the related optimization problem and propose two solving approaches to address it: a mixed-integer linear program and a heuristic based on graph theory by decomposing the time horizon in sub problems for large instances. Simulations based on real data of a French telecommunications operator prove the relevance of using batteries to reduce the energy cost for the company by participating in the demand-response mechanism. The proposed heuristic proves to be economically relevant and computationally efficient, being a good alternative to a mixed-integer program for large-scale problems.

■ MC-48

Monday, 12:30-14:00 - Virtual Room 48

Leen Stougie

Stream: Keynotes
Keynote session
Chair: *Roel Leus*

1 - Scheduling over scenarios
Leen Stougie

Scenarios are basic ingredients of optimization problems under uncertainty. Usually, they are specified only implicitly, e.g. as ranges over parameter values. Together with a distribution function over the scenarios, they lead to stochastic optimization problems. A classical model here is the stochastic linear optimization problem. A popular approximation method is the Sample Average Algorithm, which samples scenarios and optimizes over them. Moreover, the value of data is more and more recognized, which may also lead to reckon with scenarios that occur in problems more or less frequently. Anyway, if in this model scenarios are specified completely and individually, then the problem can be formulated as an LP problem, blown up with the scenarios. As a result, the problem remains polynomially solvable. We wish to investigate if this is a common phenomenon or if complexity of problems can change if scenarios are introduced into a problem. We do so at the hand of studying, most prominently, basic scheduling problems. In such problems we are given a set J of jobs, each with its processing time, a set of parallel identical machines and a set of k scenarios, where each scenario is specified as a subset of jobs in J that must be executed if that scenario occurs. The goal is to find an assignment of jobs to the machines that is the same for all scenarios, i.e., if a job does not occur in a scenario it is simply skipped. We consider the classical scheduling problems of minimizing the makespan and minimizing the sum of the jobs' completion times. For each scheduling objective we consider minimizing the maximum over all scenarios (robust version) and minimizing the average over all scenarios (stochastic version). We show that the presence of scenarios may indeed increase the complexity of the problems significantly. As a dramatic example, we mention the ordinary, single scenario, version of the makespan problem with all processing times equal to 1, which is a trivial problem. With scenarios the robust version of the problem becomes inapproximable within ratio 2 unless P=NP. This is even more surprising once one realizes that putting all jobs on one machine already yields a 2-approximation. Similar results hold for the sum of completion times problem. As for the makespan problem, the leap in complexity requires that the number of scenarios is part of the input. However, I will give an example of a scheduling problem that is in P in its ordinary version and becomes NP-hard already for 3 scenarios. We will complement these negative results with some special cases of the problems that can be solved efficiently, and an intriguing open question. The results in this lecture show the mysterious role that scenarios play in the complexity of combinatorial optimization problems. This is based on work in collaboration with Thomas Bosman (Booking.com), Martijn van Ee (Marine Academy), Esteban Feuerstein (UBA), Alberto Marchetti-Spaccamela (LSUR), Frans Schalekamp (Cornell), Rene Sitters (VU/CWI), Suzanne van der Ster (Ahold), Anke van Zuylen (Cornell)

■ MC-49

Monday, 12:30-14:00 - Virtual Room 49

AI4RAILS I

Stream: The 2nd International Workshop on Artificial Intelligence for RAILwayS (AI4RAILS)
Invited session
Chair: *Nikola Besinovic*

1 - Ant colony optimization: improved performance for train routing in complex rail networks

Bianca Pascariu, Marcella Samà, Paola Pellegrini, Andrea D'Ariano, Dario Pacciarelli, Joaquin Rodriguez

The real-time Railway Traffic Management Problem (rtRTMP) is the problem of de-tecting and solving time-overlapping conflicting request done by multiple trains on the same track resources. It consists in re-timing, reordering or rerouting trains in such a way that the propagation of disturbances in the railway network is minimized. The rtRTMP is an NP-Hard problem and finding good strategies to simplify its solution process is para-mount to obtain good quality solutions in a short computation. Solving the Train Routing Selection Problem (TRSP) aims to do so, by limiting the number of routing variables through a pre-processing that selects the most promising routing alternatives among the available ones for each train in order to reduce the size of rtRTMP instances. This paper improves the performance of an Ant Colony Optimization (ACO) algorithm for the same problem. We first generalized the cost computation in the TRSP model to better represent complex rail networks, like that of a complex node. Then, we use parallelism both to speed up ACO algorithm, and to diversify the local search used in its daemon actions in order to escape from local minima. We analyze the impact of the proposed TRSP model and algorithm refinements on the rtRTMP solutions through an extended campaign of computational experiments on a French case study. Experimental results are promising: the TRSP model refinements and the upgraded ACO-TRSP algorithm improve the quality of the rtRTMP solutions.

2 - Predicting Key Figures of Rail Freight Service Networks with Machine Learning

Tobias Pollehn, Daniel Haalboom

In consolidation-based production forms of rail freight transport, commodities are routed through a hub-and-spoke network using several consecutive trains. The Service Network Design (SND) determines the train services that are operated in the network as well as the routing of the commodities via these services. As SND models simultaneously address the intertwined decisions concerning the routing of commodities and the operation of train services, optimizing SND problems with considerable network size is time consuming. Especially when conducting scenario analysis, this is a major drawback as the calculation of numerous instances is required. We tackle this issue by applying machine learning algorithms to the SND of rail freight. Instead of optimizing each problem instance, we use machine learning algorithms to predict the values of key figures of the service network such as costs and service structures. We train different machine learning algorithms with SND solutions found from mathematical optimization and evaluate their performance. Our computational experiments indicate the high accuracy of the predictions demonstrating the gains of applying machine learning to the SND of rail freight.

3 - A Hybrid VNS-TS Algorithm for an Integrated Railway Rescheduling and Rerouting

Banafsheh Khosravi, Kullachet Korpattanachaijaroen, Djamila Ouelhadj

Disruption management is of high importance to the railway operating companies facing the increasing passenger demand. Therefore, train dispatchers need to respond to disruptions occurring in daily railway operations by rescheduling and rerouting trains. In this study, we address integrated train rescheduling and rerouting problem, which can be implemented in operational level planning. The integrated railway scheduling and routing problem is formulated as a Modified Parallel-Machine Job Shop Scheduling (MPM-JSS) model to minimize total delay in the railway network. A novel hybrid metaheuristic which combines a Variable Neighborhood Search (VNS) algorithm with Tabu search (TS), called VNS-TS, is developed to solve the mentioned problem. We conduct computational experiments to evaluate the performance of the suggested optimization model and the VNS-TS algorithm. The computational experiments investigate a real-world case study of London Bridge area in the UK railway network, which considers different disruption scenarios including blocked tracks on a single-track section, blocked tracks on multiple-track sections, and longer running or dwell times. The results show the effectiveness of VNS-TS algorithm in terms of the solution quality compared to the optimization model implemented by CPLEX.

4 - A Reinforcement Learning Approach for Railway Scheduling

Cedric Steinbach, Arturo Crespo Materna

The process of scheduling railway operations as well as the adjustment of scheduled operations are very complex. In both processes, conflicts between train operations as well as due the unavailability of resources must be resolved while taking into account their influence on the rest of the operations (i.e. follow-up conflicts). The automated adjustment of the scheduled railway operations is the subject of current research. State of the art approaches are often supported by exact methods built through hard boundary conditions or heuristic approaches that do not guarantee an optimal solution. However, Machine Learning methods have received less attention so far. This work describes an algorithm for solving conflicts, and thus, adjust a schedule using a reinforcement learning approach. This strategy can be used to perform an adjustment of the schedule in real-time or as a tool during the scheduling process. To solve the conflicts, the elemental solutions "shift train in time" and "rerouting" trains within train stations are used. The target state is a conflict-free schedule, whereby the resulting waiting times are to be minimized. The infrastructure model used is based on an established, macroscopic model. The infrastructure itself is fixed and only the operating programs are varied. Finally, the learned conflict solution strategy is tested against a state of the art heuristic, whereby the previously described framework already corresponds to the original use of this heuristic.

■ MC-50

Monday, 12:30-14:00 - Virtual Room 50

Financial modelling: its impact on society beyond Finance

Stream: Memorial Session - in honour of Jaap Spronk
Invited session
Chair: *Onno Steenbeek*
Chair: *Constantin Zopounidis*

1 - Jaap Spronk: Scholar, gentleman and Consultant
Jyrki Wallenius

In this talk I will focus on some of the highlights of Jaap's career as professor, leader, and consultant. Jaap served as professor of finance at Rotterdam School of Management for over three decades. Two decades he served as the department head. Jaap was active in the International Society of Multiple Criteria Decision Making, European Working Group on Financial Modelling, and EURO. Among other things, he served a term as President of EURO in the 90's. His research was at the interface of Finance and Management Science, and Multiple Criteria Decision Making in particular. I will also make an attempt to characterize Jaap as a person. My talk is based on personal recollections.

2 - Climate risks for sovereign debt in Europe
Stavros A. Zenios

The climate risk exposure of EU sovereigns may seem distant and indirect. It is nevertheless material. It can be acute, from extreme weather, or chronic, from gradual temperature increase and the transition to low-carbon economy. Climate-related innovations also create growth opportunities. Climate risk uniquely affects sovereign debt, which is a long-term asset class backed by revenues from an entire economy fully exposed to climate changes. Governments and fiscal stability authorities have an interest that the implications of climate change on sovereign debt are transparent. We discuss the transmission channels from climate to public finances, and identify a need for an assessment of the climate-debt nexus by the EU institutions mandated with fiscal stability. Transposing climate scenarios into sovereign debt dynamics is possible with the use of integrated assessment models, as pioneered by Nordhaus, to generate narrative scenarios and stress test debt dynamics. We use the RICE and WITCH models to illustrate the effects of climate risk on the debt dynamics of a high-debt EU member State. The results highlight the climate risk of debt dynamics and the analytical insights obtained by integrating climate models into debt sustainability analysis.

3 - Multifactor model for failure prediction
Dominicus Van der Wijst

This presentation revives the idea of using the multi-factor model for failure prediction. The model relates cash balances to a number of risk factors and uses cash insolvency as a measure of failure. Thus, failure is conditioned on the developments in the external risk factors. Since each firm is likely to have its own combination of sensitivities to the risk factors, failure is also conditioned on the specific risk profile of the firm. This gives a very transparent model that offers a natural connection with management tools, e.g. to manipulate the sensitivities. The multi-factor model was one of Jaap Spronk's favourites, and applying it to new areas is a connecting element of much of his research.

4 - Multiple Criteria Decision Aid in Finance.
Constantin Zopounidis

To be added

■ MC-51

Monday, 12:30-14:00 - Virtual Room 51

OR in Military, Defense, and International Security

Stream: OR in Military, Defense, and International Security
Invited session
Chair: *Yael Deutsch*

1 - On efficient algorithms for finding efficient salvo policies
Martijn van Ee

We consider the salvo policy problem, in which there are k moments, called salvos, at which we can fire multiple missiles simultaneously at an incoming object. Each salvo is characterized by the hit probability of a single missile. After each salvo, we can assess whether the incoming object is still active. If it is, we fire the missiles assigned to the next salvo.

In the salvo policy problem, the goal is to assign at most n missiles to salvos in order to minimize the expected number of missiles used. We consider three problem versions. In Gould's version, we have to assign all n missiles to salvos. In the Big Bomb version, a cost of B is incurred when all salvos are unsuccessful. Finally, we consider the Quota version in which the kill probability should exceed some quota Q.

We discuss the computational complexity and the approximability of these problem versions. In particular, we show that Gould's version and the Big Bomb version admit pseudopolynomial time exact algorithms and fully polynomial time approximation schemes. We also present an iterative heuristic for the Quota version, and show that a related problem is NP-complete.

2 - A Branch-and-Price Algorithm to Solve the Ship-to-Shore Problem
Mette Wagenvoort, Krzysztof Postek, Paul Bouman, Tim Lamballais Tessensohn, Martijn van Ee

After a hurricane, for example hurricane Irma at Sint-Maarten, the navy can provide aid by bringing supplies, helping to clear roads and evacuating victims. If the destinations cannot be reached over land via a port, resources can be transported using smaller ships and helicopters, called connectors. This has to be done efficiently such that the evacuation can start as soon as possible. Planning such an operation is known as the ship-to-shore problem, which is a combination of a heterogeneous vehicle routing and a bin-packing problem. The aim is to schedule the connector trips to the shore and determine what resources should be loaded onto the connectors for each of their trips while minimising the duration of the operation. Connectors have different sizes, weight capacities, speeds and (un)loading times. As the connectors make multiple trips and can visit the same location multiple times, a time-space network is used to model the problem. The size of the network is partially determined by the number of time periods needed, which is set using a greedy heuristic. The usage of the time-space network gives flexibility as it allows for increasing the number of big decks and beaches, adding different routes between the locations, and for replanning during an operation. Given a set of feasible loadings for the connectors, we solve the problem using a branch-and-price algorithm and compare its performance to a greedy heuristic. We use data provided by the Royal Netherlands Navy.

3 - The Unit Re-balancing Problem
Robin Dee, Armin Fügenschuh, George Kaimakamis

We describe the problem of re-balancing a number of units distributed over a geographic area. Each unit consists of a number of components (e.g., people, armor, or equipment). A value between 0 and 1 describes the current rating of each component. By a nonlinear function this value is converted into a nominal status assessment. This allows a comparison of different components of all units. The lowest of the statuses determines the efficiency of a unit, and the highest status its cost. An unbalanced unit has a gap between these two. When too many units are unbalanced, the entire system is costly and inefficient. To re-balance the units, components can be transferred. The goal is to have all units equally well equipped at the lowest possible cost. On a secondary level, the cost for the re-balancing should also be minimal. We present a mixed-integer nonlinear programming formulation for this problem, which describes the potential movement of components as a multi-commodity flow. Nonlinear constraints are needed to obtain the lowest and the highest status. Since we assume that these functions are piecewise linear, we reformulate them using inequalities and binary variables. This results in a mixed-integer linear program, and numerical standard solvers are able to compute proven optimal solutions for instances with up to 100 units. We present numerical solutions for a set of test instances and a bi-criteria objective function, and discuss the trade-off between cost and efficiency.

4 - To Profile or Not to Profile?
Yael Deutsch, Arieh Gavious

Developing effective inspection processes at border crossings in order to identify violators within large groups of mostly innocent people is an important and difficult task. Passenger profiling is a tool used to deal with this task, but it raises many public concerns and ongoing debates about its usefulness. In this paper, we study whether profiling is helpful, and how it should be used to maximize its effectiveness. We consider several defender-attacker game models that take place at a crowded border crossing, where passengers are divided into different groups. The defender decides on an inspection policy regarding the groups of passengers. The attacker decides whether to recruit a single passenger as a violator. The recruited passenger has a private motivation for violating that dictates his/her final action. Analysis of the equilibrium solutions identifies conditions that determine which inspection policy is better in terms of social utility and the players' payoffs.

■ MC-52

Monday, 12:30-14:00 - Virtual Room 52

Organizational and Information Management 2

Stream: Organizational and Information Management
Invited session
Chair: *Joanna Majchrzak*
Chair: *Gerhard-Wilhelm Weber*

1 - Fickle affiliations: The impact of social network change on player behavior in online games
Catalina Stefanescu-Cuntze, Vlada Pleshcheva, Francis de Véricourt

Does the affiliation with online social entities impact players' behavior in online games in a freemium model? Many online games offer in-game social structures in an attempt to foster game engagement and ultimately convert the players to the premium features. In this paper, we study how the characteristics (such as intensity, duration, and frequency) of players' affiliation to in-game social structures impact the player's behavior, in particular their propensity to compete and to purchase premium game features. We analyze a large-scale dataset on user behavior in online games, where users are part of formal online structured communities, and their engagement with the game is mediated by their overall community experience. We investigate the psychological factors that influence a player to join such a community, as well as those that may make them to churn and switch to other online communities (such as novelty or status seeking). We then explore if community membership and relative community status performance influence player behavior as evidenced through purchase intensity. We estimate structural models where the users willingness to pay for advanced features of the game is a function of engagement with the game and loyalty to the in-game social structures. We find that "switchers" (players who sequentially change club memberships rather than staying loyal to one single club) have higher purchase likelihood and higher engagement with advanced game features.

2 - Efficient algorithm for scheduling of periodic messages in large networks
Marek Vlk, Zdenek Hanzalek, Katerina Brejchova

This paper shows an application of operations research methods in the area of time-deterministic communication protocols. Thanks to the IEEE Time-Sensitive Networking task group, the real-time and safety-critical demands in various cyber-physical systems can be based on the Ethernet today. Namely, deterministic nature and timeliness guarantees can be achieved by time-triggered communication schedules enabled by the IEEE 802.1Qbv standard. However, generating such a schedule is a computationally challenging task due to several harsh constraints that must be satisfied. In particular, since switches contain queues, the frame isolation must be enforced such that one frame can only be enqueued after the other frame is dispatched from the queue. This constraint makes the problem akin partly to the job-shop problem with blocking operations and partly to job-shops with unit capacity buffers. This scheduling problem is usually transformed into some existing formalism, e.g., SMT, and solved using a general third-party solver, which has the drawback of limited scalability. We developed an efficient algorithm that does not use any third-party solver and is based on the search in the space of partial schedules while being guided by the discovered conflicts. Our algorithm synthesizes schedules for problem instances consisting of 2000 network nodes and more than 10000 flows. This work was funded by the EU Structural funds and MSMT project Cluster 4.0 CZ.02.1.01/0.0/0.0/16_026/0008432.

3 - Digital Transformation of Tourism SMEs in Greece
Christos Ziakis, Maro Vlachopoulou

Tourism is one of the most prominent industries in Greece amassing more than 1.5 billion tourists during 2019. For Greece, tourism is pivotal in propelling the Greek economy as it reflects almost 20% of the gross domestic product. Greek tourism faces a big challenge regarding its digital reform as Greece is ranked towards the bottom amongst European countries and their digital readiness for business. This article initially conducted a literature review around technologies employed by tourism businesses; it focused on digital marketing as well as on emerging technologies such as IoT, AR, AI, Big Data, Blockchain and Cloud Computing. It then presented primary research findings around small and medium-sized hotels. Research focused on the current digital state of businesses as well as their views regarding both the benefits and the challenges around digital technologies. Findings indicated that very few businesses had a complete plan for digital transformation; with regards to emerging technologies, even fewer businesses used these, whilst only some planned to invest in them in the coming year. Furthermore, the biggest benefit from using such technologies was identified around higher rates of customer satisfaction; in line with this, the complexity of the digital reform process was highlighted as the most prominent reason why businesses had not advanced towards this.

4 - OptaPlanner - an enterprise open source constraint solver for VRP, shift rostering, etc
Geoffrey De Smet

OptaPlanner is an open source constraint solver used around to globe to generate schedules that impacts millions of people's lives for the better, every day. It's well known in the programming world, but far less in the academic world.

In this session, I'll explain and demonstrate how to implement constraints in OptaPlanner and show how it scales on various use cases, such as the Vehicle Routing Problem, Shift Rostering and School Timetabling.

■ MC-53

Monday, 12:30-14:00 - Virtual Room 53

Specific Applications of Stochastic Modeling and Simulation in Engineering, Management and Science 3

Stream: Specific Applications of Stochastic Modeling and Simulation in Engineering, Management and Science
Invited session
Chair: *Ioannis Baltas*
Chair: *Athanasios Yannacopoulos*

1 - Designing the Biomass Supply Chain for Biorefinery Location Problem Using Stochastic Optimization
Aitor Ballano Biurrun, Adrian Serrano, Javier Faulin, Luis Cadarso

Nowadays, biofuels are evolving as renewable and sustainable energy sources, especially on developed countries, due to the neutral CO2 emissions within their complete cycle. Regarding this topic, a biorefinery, is considered to be sited in Northern Spain. The problem considers uncertainty in biomass prices and availability therefore, a stochastic optimization approach is needed to reduce the project risks. The optimization is represented as a three-stage scenario tree, composed of strategic and tactical nodes. The former refers to location of the biorefinery, while the latter refers to the rent of different warehouses. Additionally, operational nodes are rooted to the strategic and tactical nodes forming different two-stage operational scenario trees. In these operational nodes, decisions related to the biomass acquisition are made. Meaningful insights are obtained from the application of stochastic optimization at all levels: strategic (the facility location problem), tactical (warehouses strategy) and operational (biomass purchases), highlighting a superior performance than the deterministic equivalent model.

2 - Decision-making in HHC: state-of-the art and integrated model
Arne Delaet, Kris Braekers, Yves Molenbruch, Katrien Ramaekers

Home health care (HHC) is an important component of the health care industry and may be defined as care workers visiting patients following predefined schedules in order to provide medical services in their home. Maintaining a sustainable and effective health care system is a major challenge as a result of two trends: limited resources (budget restrictions and staff shortage) and a rise in demand. In response to these trends and increasing competitive pressures, HHC providers must discover new ways to decrease costs and enhance productivity by optimizing the use of resources. For this reason, applying operations research techniques in HHC is a promising research field.

In this context, a key opportunity for improvement is the integration of decisions at different decision-making levels. More specifically, the goal of this research is to develop innovative models and solution algorithms that enable making better decisions on staffing levels by integrating staff dimensioning, rostering, clustering, scheduling and routing decisions.

First, this talk will discuss the main findings of a literature review on operations research models that integrate decisions at multiple decision-making levels. Second, a first MIP model focussing on the integration of the aforementioned decisions will be discussed.

3 - Optimal management of defined contribution pension funds under the effect of inflation, mortality and uncertainty
Ioannis Baltas, Athanasios Yannacopoulos, Marek Szczepanski, Gerhard-Wilhelm Weber, Lukasz Dopierala, Krzysztof Kolodziejczyk

We study the problem of optimal management of defined contribution pension funds, during the distribution phase, under the effect of inflation, mortality and model uncertainty. More precisely, we consider a class of employees, who, at the time of retirement, enter a life assurance contract with the same insurance firm. The fund manager of the firm collects the entry fees to a portfolio savings account and this wealth is to be invested optimally in a Black-Scholes type financial market. As such schemes usually last for many years, we extend our framework, by: (i) augmenting the financial market with an inflation-adjusted bond, and, (ii) taking into account mortality of the fund members. Model uncertainty aspects are introduced as the fund manager does not fully trust the model he/she faces. By resorting to robust control and dynamic programming techniques, we provide: (a) closed-form solutions for the case of the exponential utility function, (b) a detailed study of the qualitative features of the problem at hand that elucidates the effect of robustness and inflation on the optimal investment decisions.

4 - An meta fuzzy functions integrated mixed vehicle routing approach for coast guard patrol management project in turkey
Fatma Çarman Çevik, Ceren Tuncer Sakar

We study a patrol vehicle routing problem for the first time within a maritime line security project in Turkey. By detecting the migration movement in advance, it can be ensured that the Coast Guard Command follows an efficient patrol route and thus the detections of immigrants can be increased. Therefore, the problem requires efficient and effective approaches. To provide this, we propose routing solutions where points of interest can have different levels of criticality. We first determine the demand points of the problem. For this, we cluster the coordinates of immigrants detected between 2015-2019 with the K-Means clustering algorithm. We take the cluster centers obtained as a result of clustering as the demand points of the routing problem. To determine the criticality levels of the demand points, we estimate the expected number of immigrants for the points with Forecast Combination with Meta Fuzzy Functions (FC-MFFs). We use these forecasts as the significance weights of the points. Then, we propose a MFFs based approach and apply to a real life problem in the defense industry. Using five different pilot areas, we first solve the traditional mixed vehicle routing model to minimize the overall distance. Next, we consider the partial vehicle routing model. Thus, we obtain a effective patrol vehicle route that provides maximum detection according to the expected number of immigrants. The MFFs based approach is a contribution to the integrated perspective literature.

■ MC-54

Monday, 12:30-14:00 - Virtual Room 54

Performance Measurement, Valuation, Financial Planning

Stream: Operational research in financial and manage-

ment accounting
Invited session
Chair: *Matthias Amen*

1 - Generation of fixed plans from financial planning under uncertainty
Matthias Amen

In modern financial planning it is possible to consider explicitly uncertainty. This can be done by means of Monte Carlo-simulation techniques. Given (empirical or artificial) distributions of parameters or stochastic relations between inputs, throughputs and outputs of the production process, we will get distributions for the final results, e.g. profit or cashflow.

Therefore we are faced with two sequential problems:

(a) From the planning perspective we have to maximize the profit. In case of a distribution of profit we should fix the decision variables in way to maximize the expected value of profit with respect to some restrictions.

(b) Once we have fixed the decision variables, we have to work with a non-stochastic plan due to requirements of jurisdiction. We are forced to work with best possible assumptions (ISAE 3400.4). Furthermore, it is easier to communicate - internally and externally. That means, that we have to transform the result of (a) into a documented plan with fixed values for parameters, throughputs, outputs and the final results. Of course, even with fixed decision variables there is a variety of possible combinations of throughputs and outputs to get the communicated final results. That means that we have to fix the throughputs and outputs with respect to their distribution.

In the presentation we will discuss the problem and focus on aspect (b).

2 - Assessing and improving accounting based company valuation
Lukas Benjamin Heidbrink

The usefulness and predictive power of accounting data, especially earnings and cash flow figures are of great interest for researchers and investors alike. I test the Feltham-Ohlson model and its information dynamics framework in terms of its predictive performance and compare it to other established models. The empirical evaluation reveals a significant number of non-stationary time series and cointegrating relations within time series for each company. Although this has already been discovered, proposed remedies do not provide satisfactory results in many cases within the sample. I find that normalizing the data does not lead to stationarity in most cases. Hence, inference drawn from earlier studies utilizing data from US companies could be misleading and not suitable for data from other companies and periods of time. Therefore, I compare the predictive power using different settings and remedies for non-stationarity as well as data in levels and normalized data. The linear information system will be modified with other time series and evaluated using different forecasting horizons. I present benefits and shortcomings of the framework as well as univariate modeling alternatives.

3 - Investment Timing of CSR-Investments: A Structural Estimation Model
Stefan Kupfer, Elmar Lukas, Sascha H. Moells, Vladlena Prysyazhna

We study the relation of uncertainty and investment in corporate social responsibility (CSR) measures under different corporate governance regimes based on an analysis of the hazard rate of investment. Corporate non-financial reporting on sustainability increased over the last years and together with increasing pressure from corporate governance as well as public interest may trigger investment even in the face of uncertain sustainability trends. Companies may build up cash holdings to time these projects and to mitigate external financing as well as retain earnings to sustain projects. We use a dynamic investment model with cash holdings as well as costly external funds to analyze the hazard rate of investment and the effect of uncertainty in such a setting. Based on a unique dataset of CSR reporting of 653 companies from 9 industrialized countries in the time period from 2003 to 2017 supplemented by corporate governance and financial data we calculate the maximum likelihood estimates of the hazard to invest in CSR projects in practice. The option value of waiting and the effect of uncertainty are analyzed using a structural estimation of the option-based hazard. Our results contribute to the understanding of why and how companies invest in and report on CSR projects and the moderating role of corporate governance.

4 - Do Women on Corporate Boards Affect Firm Performance? An International Empirical Study
Mengyang Ma, Sascha H. Moells, Vladlena Prysyazhna

Diversity gained an increased attention among academic scholars, practitioners and regulatory bodies in the last decades with a particular emphasis given to female representation and its relevance for firm performance. However, theoretical and empirical results are ambiguous with primary attention being paid to the board of directors. In contrast to much of prior research, we differentiate the analysis and investigate the effect of female representation on management board, supervisory board and board of directors on firm performance. Our study is based on a sample of the biggest 100 publicly traded corporations of 15 industrialized countries covering the years 2010 and 2015, which results in around 1500 observations per year. Data on female representation and other corporate governance attributes are all hand-collected and derived for both reference years based on the annual documents published by the firms. By applying a quantile regression, we find that female representation on supervisory boards has a significant impact on the volatility of market-based performance, suggesting that the characteristic of risk-aversion predominantly attributed to females might be advantageous at the supervisory level. In addition, we show that higher female representation on supervisory bodies is primarily beneficial for lower-performing firms. The absence of significant effects for management boards in general might occur due to a low average fractions of females on these corporate bodies.

Monday, 14:30-16:00

■ MD-01

Monday, 14:30-16:00 - Bulding A, Amphitheatre

Optimal Control Theory and Applications 2

Stream: Optimal Control Theory and Applications
Invited session
Chair: *Fausto Gozzi*
Chair: *Maria Lavrutich*

1 - Time-space evolution of economic activities: a mean field game model
Fausto Gozzi, Giorgio Fabbri, Davide Fiaschi, Daria Ghilli, Cristiano Ricci, Giovanni Zanco

The goal of this talk is to present a review of recent models on the time evolution of most important economic variables (e.g. labour and capital) across different locations, taking into account space heterogeneity. In particular we focus on two recent works (partly in progress): - one looking at the macro level where there is one planner which, in a spatial Ramsey setting, maximizes utility across space with heterogeneous productivity. - one looking at the micro level where the agents move across space maximizing their own utility which also depend on the position of the other agents.

2 - Advertising, goodwill, and the Veblen effect
Régis Chenavaz, Amit Eynan

The increase of demand in price, an exception to the law of demand, is known as the Veblen effect. In this work, we consider a profit maximizing monopoly which by means of advertising impacts the price-demand relationship. We show that advertising and goodwill play an important role in making the Veblen effect more prevalent than expected. By employing optimal control theory we capture the evolution of the variables over time which may exhibit the Veblen effect where price and demand move in the same direction. Incorporating this dynamics into firms' decisions has a promising impact on long-term profit. Consequently, it may even trigger a slew of studies on product line extension, competition and pricing by allowing firms to control their status.

3 - Exchange of energy among prosumers under prices uncertainty
Marta Castellini, Luca Di Corato, Michele Moretto, Sergio Vergalli

Abstract Our paper provides a theoretical real options framework for modeling prosumers' investment decisions in photovoltaic plants in a Smart Grid context, when exchange of energy among prosumers (exchange P2P) is possible . We focus on the optimal size of their photovoltaic plants and on the self-consumption profiles the prosumers must comply with to assure the demand and supply matching in P2P exchange. The model was calibrated to the Northern Italy energy market. We investigate the investment decision under different prosumers' behaviors, taking into account all the possible combinations of their energy demand and supply. Our findings show that the existence of the exchange of energy among prosumers is not assured in all the cases we have focused on, but depends on the shape and relationship between the supply and demand curves of the two prosumers. The best situation is when the two prosumers have an excess of supply and asymmetric and perfectly complementary demand curves. Sub-optimal cases occur when the exchange P2P and the sell to the national grid are exploited advantageously. This scenario is profitable if there is efficient cooperation between the two agents in exchange choices. Furthermore, prosumers invest in the highest capacity when they are characterized by different exchange P2P and self-consumption profiles, and they reach the maximum gain from the investment in a context characterized by excess supply in exchange P2P

4 - Predatory pricing and the value of corporate cash holdings
Maria Lavrutich, Jacco Thijssen

We analyze the interaction between firms' payout policies and their decisions in product markets in a continuous-time stochastic game between two firms. One firm is financially constrained, whereas the other is not. Contrary to the standard literature we allow firms to choose both production and payout strategies, and focus on the effect of predation incentives on both. We find that predation induces fewer dividend payouts. Furthermore, the liquidity position of the constrained firm has an economically significant effect on the production choices of both firms and, thereby, on the evolution of profits, cash holdings and stock returns.

■ MD-02

Monday, 14:30-16:00 - Bulding A, Room A5

Workforce Scheduling and Line Balancing 1

Stream: Scheduling and Project Management
Invited session
Chair: *Evgeny Gurevsky*
Chair: *Alexandre Dolgui*
Chair: *Simon Thevenin*
Chair: *Nadjib Brahimi*
Chair: *Carla Talens Fayos*

1 - A novel acceleration procedure for the assembly flow shop scheduling problem
Victor Fernandez-Viagas, Carla Talens Fayos, Jose M Framinan

In this paper, we address the assembly flow shop scheduling problem to minimize the makespan. In this problem, each component of a job is first processed in a phase composed of several dedicated machines, and then the job is assembled in a second phase that can be modelled as a flow shop with several machines. This problem is a generalization of the two- and three-stage assembly scheduling problems. For this problem, we propose an acceleration procedure based on several properties of the problem. This procedure is incorporated into novel constructive heuristics, which are compared against the most promising heuristics of the related literature. The results show the excellent performance of the proposals.

2 - Online sequencing of buffers for automotive assembly lines
Malte Lübben, Celso Gustavo Stall Sikora, Sven Pries

Mixed-model assembly lines are widely used in the automobile industry. Manufacturers face the challenge to produce a huge number of models while using the relatively inflexible but efficient production form of an assembly line.

In this work, we consider the usage of a buffer (in form of an automated storage and retrieval system) in a paced assembly line between the paint shop and the final assembly (FA) to resequence the orders. The altered sequence can be restored by another buffer downstream the final assembly. We also consider a high number of variants, which is why the properties of the product that enters the first buffer cannot be foreseen. Following this, the selection, which of the products will be passed to the FA, must be made without full information in an online problem. To solve this problem, we apply different heuristics to a simulative environment and focus upon a limited lookahead algorithm with the aim to minimize the amount of utility work.

3 - Multi-period crew scheduling for the regular round trips in the road freight transportation
Aleksejs Lozkins, Mikhail Krasilnikov, Andrey Logachev, Nkolay Rychkov

The problem of crew scheduling for the regular round trips consists of finding the most efficient duty combination to cover all road freight transportation activities for the defined period of time and satisfying legal requirements. We consider the problem of minimum amount of drivers serving a set of long-haul trips, where single trip is fulfilled by the sequence of changing crews. Aggregation constraints, such as one/two week work time and weekly rest requirements, make the crew scheduling problem more sophisticated due to several weeks planning horizon. We present a set partitioning and a network flow models for the crew scheduling on the regular long-haul trips to solve instances optimally and to improve solutions of real-world instances. In addition, we apply different valid inequalities to network flow model and perform computational tests to evaluate their influence on the computational time. Furthermore, we present computation instances implemented according to legal requirements for long-distance haulage in the Russian Federation. Also we study the single or team driving and the schedule periodicity impacts on the final schedule cost.

4 - The two-stage assembly scheduling problem with periodic maintenance: New approximate methods
Carla Talens Fayos, Victor Fernandez-Viagas, Paz Perez Gonzalez

In this study, we analyse the two-stage assembly scheduling problem, where there are m dedicated parallel machines in the first stage and one assembly machine in the second stage, with periodic maintenance and the objective of minimising makespan. In this problem, the scheduling horizon is composed of periods where the machines are available followed by other periods where no operation can be performed. Several heuristics proposed to solve related problems have been adapted to the problem under study and compared by carrying out a computational evaluation. Additionally, we propose two new heuristics and a composite local search mechanism to solve the problem. The computational results show the efficiency of the proposed heuristics.

■ MD-03

Monday, 14:30-16:00 - Bulding A, Room 3A

The Role of Mathematical Optimization in Data Science VI

Stream: Mathematical Optimization and Data Science
Invited session
Chair: *Veronica Piccialli*

1 - A bi-objective K-nearest neighbors based imputation method for data with multilevel structures
Maximiliano Cubillos, Sanne Wøhlk

In this paper, we propose a bi-objective algorithm based on the k-Nearest Neighbors method to perform imputation of missing values for data with multilevel structures with continuous variables. We define the imputation method as a bi-objective minimization problem and propose a solution algorithm based on a weighted objective function. The algorithm seeks imputed values that balance the dissimilarity between the k-Nearest Neighbors and the observations within the same cluster. The effectiveness of the proposed method is based on a simulation study and results are compared with eight benchmark imputation methods. The simulation study is based on the generation of datasets with a varying-intercept multilevel model and results are compared both by using well-known accuracy metrics and estimating the bias of the estimates after inference is performed. Based on the simulation, the effect of different configurations of multilevel datasets are tested, including: the number of clusters, the size of the clusters, the similarity of the clusters (based on intraclass correlation), the percentage of missing values, and the effect of imbalanced clusters. Results show that the proposed method can outperform the benchmark methods, especially in cases with high intraclass correlation, with an average decrease of the imputation error of 10.2%.

2 - Properties of Inverse Correspondence Analysis
Rick Willemsen, Wilco van den Heuvel

Correspondence analysis (CA) is a dimension reduction technique for categorical data in a two-way contingency matrix. The aim is to optimally depict the relationship between categories for both variables in a low-dimensional representation. We investigate inverse correspondence analysis (ICA), which uses the low-dimensional CA solution to retrieve the original data matrix. Retrieving the original data can be of interest when the original data is not available. In some cases researchers are not allowed to share the original data set if it contains sensitive information. Assuming that the original data set can be retrieved using ICA, researchers should be careful with disclosing published CA results. In previous empirical research the retrieved ICA solution always corresponds to the original data matrix. This is an unexpected result, because CA is a dimension reduction technique. Our contribution is twofold. First, we derive theoretically that ICA solutions are not always unique. We introduce matrices with a specific singular value structure for which the ICA problem has more than one solution. Secondly, an integer programming formulation is given to solve the ICA problem. We observe that not all constraints are needed to solve the model and propose a method that temporarily removes constraints. On basis of computational results we show that this method can solve larger instances compared to previous work, while still retrieving the original data.

3 - SOS-SDP: an Exact Solver for Minimum Sum-of-Squares Clustering
Veronica Piccialli, Antonio Maria Sudoso, Angelika Wiegele

The minimum sum-of-squares clustering problem (MSSC) consists of partitioning n observations into k clusters to minimize the sum of squared distances from the points to the centroid of their cluster. In this work, we propose an exact algorithm for the MSSC problem based on the branch-and-bound technique. The lower bound is computed by using a cutting-plane procedure where valid inequalities are iteratively added to the Peng-Wei SDP relaxation. The upper bound is computed with the constrained version of k-means where the initial centroids are extracted from the solution of the SDP relaxation. In the branch-and-bound procedure, we incorporate instance-level must-link and cannot-link constraints to express knowledge about which instances should or should not be grouped together. We manage to reduce the size of the problem at each level preserving the structure of the SDP problem itself. The obtained results show that the approach allows to successfully solve real-world instances up to 4000 data points for the first time.

■ MD-04

Monday, 14:30-16:00 - Bulding A, Room 3B

Organizational and Information Management 1

Stream: Organizational and Information Management
Invited session
Chair: *Michal Cerny*
Chair: *Joanna Majchrzak*

1 - Estimation of the retail chain customer base
Ondřej Sokol, Vladimír Holý

We focus on the basic retail store issue – estimation of the customer base composition. While it is common to monitor every individual transactions, it is not always possible to link such transaction to a specific customer. This is only possible if the customer identifies during the transaction, for example with a loyalty card. Therefore, two different datasets are available – one containing transactions of customers with a loyalty card and second containing the transactions made by non-identified customers. The aim of the proposed method is to estimate how many unique customers without loyalty cards visit the retail store during a given period and what is their composition. The proposed method consists of two phases. First, the archetypes of customer behavior with a loyalty card are identified. Second, the distribution of customer archetypes on the transaction dataset of non-identified customers is estimated by maximizing the likelihood. Compared to the naive method, which assumes the same distribution of archetypes in both groups, the results are superior.

2 - A Dynamic Model for Price Clustering
Vladimír Holý, Petra Tomanová, Michal Cerny

Stocks on NYSE and NASDAQ exchanges are traded with precision to one cent. Interestingly, prices ending with 0 or 5 occur much more often. In the financial literature, this phenomenon is known as price clustering and is observed across various financial instruments and markets. In the literature, however, it is rarely incorporated into price models. We assume that there are several types of agents trading only in specific multiples of the tick size resulting in an increased occurrence of these multiples in prices. To capture this behaviour, we propose a parametric model for discrete prices. The model is based on a mixture of double Poisson distributions with dynamic volatility and dynamic proportions of agent types. Parameters of the model are estimated by the maximum likelihood method. We illustrate the use of the model in an empirical study of DJIA stocks.

■ MD-05

Monday, 14:30-16:00 - Building Δ, Room Δ105

AHP/ANP Applications

Stream: AHP/ANP
Invited session
Chair: *Rocío Poveda-Bautista*

1 - ANP analysis of scientific impact of research collaboration processes through biomedical research networks
Rocío Poveda-Bautista, Hannia González-Urango, Pablo D'Este Cukierman, Oscar Llopis Corcoles, Adrián Arias Diaz-Faes

This paper aims to investigate how scientific research networks operate to deliver both scientific discoveries and applicable results. For it a biomedical research group within the biomedical research networking centers in Spain (CIBER network) is analyzed. We propose the use of The Analytic Network Process (ANP) to model this research group, and its interaction processes with relevant and divers actors, as a research network. These interaction processes will be grouped in components corresponding to distinct research phases from basic to clinical research stages. ANP will be used to analyze the influences that exist between these processes of interaction within and between each research phase considered in the study. This will allow complementarities to be identified between interaction processes that foster cohesion among network participants. This influence analysis will identify the mechanisms of scientific collaboration that contribute to greater network cohesion, and how much they should be encouraged to coordinate actor diversity in research networks. The network elements will be derived from interviews with researchers and stakeholders based on the research phases. These interviews will provide information on the interaction processes that respondents identified as relevant for strengthening cohesion in translational research collaborations. The participation of experts with various expertise in biomedical research is crucial for all stages of the ANP method

2 - A Delphi-ANP method for identifying potentially next Carbon Neutral Districts
Tomás Gómez-Navarro, David Ribó-Pérez, Isabel Aparisi-Cerdá, Monica Garcia-Melon

A method is proposed to assist in the selection of the districts with the greatest potential to become the city's first carbon neutral districts. The aim is for cities to contribute to the EU Green New Deal, the commissioner of the work is the city council of Valencia, but the method can be adapted to any city. The method is based on a combination of literature search, the Analytic Network Process (ANP) and the Delphi method. Several potential candidate districts have been selected for various reasons that are discussed. The main selection criteria have been identified and organised into clusters, and the Delphi technique has been used to prepare the application the ANP to this decision problem. The results show an initial list of 35 criteria in 5 clusters: Technical, Social, Economic, Environmental and Urban. With the work of decision-makers using the Delphi technique, the list was prioritised and the 14 most important criteria were selected, those that added 80% of the weight. Then, applying ANP, the criteria were re-prioritised, taking advantage of the previous Delphi work, and the district alternatives were ranked. The method is not only an aid to decision making for policy makers, but also helps to better understanding of the complexity of the problem and better communicating the objectives, advantages and disadvantages of these ambitious city projects.

3 - Adapting RRI Public Engagement indicators to the Spanish scientific and innovation context. A participatory methodology based on AHP and Content Analysis
Monica Garcia-Melon, Amparo Baviera-Puig

The paradigm proposed by Responsible Research and Innovation in the European Commission policy discourse identifies Public Engagement as a key area for exchange and dialogue among multiple actors following an inclusive and participatory process. Two definite set of indicators have already arisen at European level to monitor Public Engagement activities in the Science and Technology realm. Our study aims to propose a deliberative participatory process, which involves selected stakeholders, for the adaptation of the European indicators to the specific Spanish scientific and innovation context. The methodological procedure is of exploratory nature and will be based in a combination of, on the one hand qualitative content analysis techniques for the in-depth study of the deliberative process and the generation of indicators; and, on the other hand, a multicriteria decision analysis technique such as the Analytic Hierarchy Process for the prioritization of the indicators. The discussion will focus on the procedure to articulate stakeholders' values and use them as the basis for creating a context-based improved list of indicators. Two types of research questions arise: (i) Is the proposed methodology adequate for the adaptation of the European indicators to the Spanish context? (ii) What are the main indicators to monitor and to expand reflection on the public engagement in the Spanish science and innovation?

■ MD-06

Monday, 14:30-16:00 - Building Δ, Room Δ103

MILP in Manufacturing and Logistics

Stream: Mixed Integer Linear Programming
Invited session
Chair: *Fabrizio Marinelli*

1 - Optimization models for an assort-and-cut problem in glass manufacturing with defective raw material
Fabrizio Marinelli, Claudio Arbib, Mustafa Pinar, Andrea Pizzuti

In this study, we move from the necessity of optimizing the production process of a relevant manufacturing company making glass products for the automotive market. Finite products are obtained through three phases that start from cooled down melted glass, divided into large sheets, and further cut into small items. Finally, such items are bent and refinished to get the finite goods. Optimization focuses on the assortment of large glass sheets and the selection of cutting patterns: the number of different large sizes employed is limited to control setups and warehouse holding costs, while cutting operations are performed to minimize the resulting waste. Still, some areas of the glass sheets can occasionally be corrupted by the presence of defects, becoming unusable for finite good production. Two mathematical programming formulations, taking into account the stochasticity of defect existence, are proposed: a robust formulation based on appropriate Bertsimas-Sim uncertainty set, and a bi-level optimization model. Both models can be reduced to a standard mixed-integer program, the former aiming at the minimization of the overall wasted material generated by trim and defect losses under assortment and demand constraints; the latter pursuing the maximization of production yield under assortment and material restrictions. Computational experiments were performed to analyze the quality of the proposed models for the solution of realistic instances.

2 - Optimizing the Locations of JIT/JIS Supermarkets in Automotive Production Plants

Heinrich Kuhn, Marcel Lehmann, Mareike Mueller

The current trend towards an increased number of models and variants in the automotive industry leads to a rising logistical effort to supply the mixed model assembly lines daily. Therefore, so called supermarkets are installed to feed the assembly areas by using different JIT applications. Parts and subassemblies must be assigned to these areas located inside and outside of the manufacturing plant. We provide a description of the supermarket concept in a single- and especially multi-line automotive manufacturing plants and the related location planning problem.

The problem is formulated as Mixed Integer Linear Program (MILP) and solved by a standard solver. The applicability is shown in a case study based on a real-world data set provided by a German premium car manufacturer. We show the benefits of the mathematical planning approach for supermarket allocation including managerial insights generated throughout the execution of the case study. The model provided generates two figure percentage cost savings compared to the manually created solution applied at the car company.

3 - Benders decomposition for the balancing of assembly lines with collaborative robots

Celso Gustavo Stall Sikora, Christian Weckenborg

Even with the automatization of several processes in manufacturing, assembly lines still strongly rely on human workers. The operation of assembly lines requires adaptability and flexibility, which is not yet achieved by large and heavy industrial robots. A newer generation of lighter robots with advanced sensors and cameras has the potential to work alongside humans in a collaborative environment. The "cobots" can be used to perform tasks sharing human workstations or even cooperate in the same task. The assembly line balancing problem consists of assigning the process tasks to multiple workstations, with the objective of equalizing the workload. We present an exact method based on Benders decomposition that solves the problem also considering the possible use of cobots. Multiple decomposition structures are tested along with a local search enhancement to accelerate the algorithm.

4 - A polyhedral approach to some max-min problems

Thomas Lidbetter

We consider a max-min variation of the classical problem of maximizing a linear function over the base of a polymatroid. In our problem we assume that the vector of coefficients of the linear function is not a known parameter of the problem but is some vertex of a simplex, and we maximize the linear function in the worst case. Equivalently, we view the problem as a zero-sum game between a maximizing player whose mixed strategy set is the base of the polymatroid and a minimizing player whose mixed strategy set is a simplex. We show how to efficiently obtain optimal strategies for both players and an expression for the value of the game. Furthermore, we give a characterization of the set of optimal strategies for Player 2. We discuss the implications of our results for problems in search theory, sequential testing and queuing.

■ MD-21

Monday, 14:30-16:00 - Virtual Room 21

Behavioural impacts from the use of decision analysis approaches

Stream: Descriptive and prescriptive behavioural OR studies

Invited session

Chair: *Johannes Siebert*

1 - The effect of disaggregating summary statistics in Web-Delphi processes: results from a real-world Delphi experiment

Liliana Freitas, Ana Vieira, Monica Oliveira, Carlos Bana e Costa

Delphi processes are participatory processes often used to collect experts and stakeholders views to inform operational research modelling. Delphi's controlled feedback feature allows individual participants to get acquainted with (eventual) new knowledge and, in sequence, revise their opinions, engaging in a knowledge construction process. Nevertheless, several studies show unexpectedly limited opinion changes occurring due to belief perseverance bias. Such bias can be avoided by recognizing expertise in the people one is interacting with, which is hindered by the aggregation of results in a Delphi environment. A real-world Delphi was conducted with different stakeholders within the scope of Health Technology Assessment to explore the effect of feeding back the distribution of the answers disaggregated per groups of stakeholders on the dropout rate and opinion change. For that, as Delphi's feedback, participants were randomly allocated to see the global distribution of the answers and comments, or that information plus the distribution of answers per group of stakeholders. Results showed that the experiment did not affect the dropout rate. No statistically significant difference between conditions was either found concerning the opinion change. Participants commenting on the disaggregation of answers considered it interesting and useful for informing their opinion. These results can impact the choice of feedback formats in future Delphi processes.

2 - Comparison of three multicriteria decision support methods in environmental portfolio selection

Jyri Mustajoki, Mika Marttunen, Arto Haara, Turo Hjerppe, Mikko Kurttila, Juuso Liesiö, Heli Saarikoski, Anne Tolvanen

Environmental management problems are often portfolio problems with an aim to select a set of actions that meet different objectives (e.g., the reduction of greenhouse gas emissions) and constraints (e.g., costs). We report experiences from applying three multicriteria decision support methods - Multi-Attribute Value Theory (MAVT), the project portfolio selection tool Your Own Decision Aid (YODA) and Robust Portfolio Modelling (RPM) - in a real environmental portfolio case. The case was an evaluation of three peatland rewetting options (restoration, damming, no action) for 79 drained peatland stands in an important recreational and nature conservation area in southern Finland. We evaluated the pros and cons of the three methods, as well as their key methodological challenges. Each method has its strengths: MAVT is able to highlight the strengths and weakness of rewetting options for a single peatland stand, YODA is simple and possible to use independently via the Internet, and RPM can determine the priority of peatland stands within constraints even without precise preference information. The methodological competency of the participating stakeholders is a key aspect in the choice of methods. We discuss the amount of facilitation needed to reduce the behavioral biases of participants using the methods.

3 - The effects of communication modality and situational complexity on strategic decision-making

Stephen Donnel, William Caballero, Brian Lunday

This research examines the degree to which communication modality and situational complexity affect an individual's ability to identify an effective strategy in a competitive environment. Human subject testing herein consists of benign, benevolent intervention wherein participants are presented a series of strategic situations corresponding to two-player, normal-form games with complete information. Dual channel theory directly informs our experimental design; it specifies both the manner in which humans process information and the existence of capacity limits fir these cognitive mechanisms. Through a computerized test instrument, participants attempt to determine the best response in dominance-solvable, normal-form games of sizes 2x2 through 5x5. Each game structure is presented via three different communication modalities: audio-only, visual-only, and audio-and-visual. Categorical data analysis techniques applied to raw response data determine the association between actions and communication modalities. We leverage the Cognitive Hierarchy model to characterize changes in the population's average level of strategic thought over varying communication modalities and situational complexities. Analysis shows that the inclusion of visual communication resulted in statistically significantly differences in participant responses and an increased level of strategic thought relative to audio-only communication, whereas the effects of situational complexity were more nuanced.

4 - Empirical evidence on the effectiveness of "giving oneself a nudge": The relative benefits of pursuing decision opportunities and solving decision problems
Johannes Siebert, Christian Hannes

Thaler and Sunstein presented a concept of how individuals can be "nudged" to make better decisions without restricting their freedom of choice.. A decision architect is essential for applying the concept of nudging. However, in many decision situations, there is no decision architect available or the decision makers do not want a decision architect, perhaps because it is a very private or confidential decision situation. Therefore, in his 2020 book Give Yourself a Nudge, Keeney extended the concept of nudging to decision situations in which there is no decision architect to nudge the decision-maker. The core idea is to empower decision makers to become their own decision architects. He provided several suggestions on how individuals can nudge themselves. Two important nudges are to create decision opportunities proactively and to convert decision problems into decision opportunities. These nudges are based on the assumption that decision makers are happier pursuing decision opportunities than solving decision problems. We conducted three studies with 731 participants to test this assumption. We gathered comprehensive empirical evidence suggesting that individuals facing decision opportunities are more satisfied in their decision situations throughout the decision-making process than individuals facing decision problems. Furthermore, our empirical findings provide the first insights about how decision makers address decision situations and their life satisfaction.

■ MD-22

Monday, 14:30-16:00 - Virtual Room 22

Multi-level optimization for energy management I

Stream: Bilevel Optimization
Invited session
Chair: *Sonja Wogrin*
Chair: *Ana Baringo*

1 - An Adjustable Robust Optimization Approach for the Expansion Planning of a Virtual Power Plant
Ana Baringo, Luis Baringo, José Manuel Arroyo

A novel approach based on adjustable robust optimization for the investment planning of a virtual power plant that participates in the energy electricity market is proposed. The virtual power plant comprises conventional, renewable, and storage units, as well as flexible demands. Investment decisions on conventional, renewable, and storage units are made under the uncertainty related to future production costs of the conventional generating units, future consumption of the flexible demands, and future energy market prices. As a major complicating aspect, the nonconvex operation of both conventional generating and storage units is precisely accounted for. The resulting model is formulated as a trilevel program with lower-level binary variables that is solved using a nested column-and-constraint generation algorithm. Results from a case study show the effective performance of the proposed approach.

2 - Risk aversion in multilevel electricity market models with different congestion pricing regimes
Adriaan Hendrik van der Weijde, Mirjam Ambrosius, Jonas Egerer, Veronika Grimm

Due to ongoing efforts for decarbonization, electricity markets worldwide are undergoing fundamental transitions, which result in increased uncertainty for all market participants. Against this background, we investigate the impact of risk aversion on investment and market operation in markets with different congestion pricing regimes and multi-level decision making. We develop a stochastic multi-level equilibrium model with risk-averse agents, which includes investment in transmission and generation capacity, market operation, and redispatch. The model can incorporate perfect, as well as imperfect locational price signals and different upper-level expectations about lower-level risk aversion. We apply our model to a stylized two-node example and compare the effects of risk aversion in a system with zonal and nodal pricing, respectively. Our results show that the effect of risk aversion is more pronounced in a market with nodal pricing, compared to a market with imperfect locational price signals. Furthermore, transmission planners that are ignorant about risk aversion of generation companies can induce substantial additional costs, especially in a nodal pricing market.

3 - Energy storage investments in view of risk aversion
Stefanos Delikaraoglou, Sonja Wogrin, Audun Botterud

The appeal for higher shares of renewable energy sources in the power system brings new technical and economic challenges to the system operators and the market participants. To address those challenges, new technologies, such as energy storage systems (ESS), are needed in order to cope with the variable and partly predictable nature of renewables' production. In this operational framework, it is imperative to consider the establishment of new market mechanisms that enhance the economic viability of those assets and mitigate the risk for the investors.

In particular, as we move towards a power system dominated by variable and stochastic renewables, electricity prices tend to become more volatile and harder to predict. In this market environment, the ESS investors need new hedging mechanisms that allow them to secure the cost recovery of their new investments. To this end, we propose a new methodological framework that allows us to investigate the impact of different risk aversion levels on the ESS investment decisions, considering also the recently introduced risk hedging mechanism of financial storage rights. The proposed framework is formulated using stochastic bi-level optimization, which allows to model endogenously the impact of investment decisions on the electricity market prices and subsequently on the investments' profitability.

4 - Managing Risks Faced by Strategic Battery Storage in Joint Energy-Reserve Markets
Hrvoje Pandzic, Kenneth Bruninx, Kristina Pandzic

Securing profits from energy, reserve capacity and balancing markets is critical to ensure the profitability of battery energy systems (BES). However, the intimate connection between offers on these trading floors combined with the limited energy storage capacity of BES renders its scheduling very complex. This talk will present a bilevel optimization problem for strategic participation of a BES in the day-ahead energy-reserve and balancing markets, improving the state-of-the-art by (i) considering the conditional-value-at-risk; (ii) ensuring the real-time feasibility of the obtained day-ahead schedule; (iii) addressing the operational underperformance risk stemming from inaccurate battery modeling. In a case study, we illustrate how the proposed model allows risk-averse BES owners to hedge their day-ahead position without jeopardizing their expected profit, while ensuring the feasibility of their day-ahead schedule.

■ MD-23

Monday, 14:30-16:00 - Virtual Room 23

Complexity and New Algorithms in Derivative-free Optimization

Stream: Derivative-free Optimization
Invited session
Chair: *Clément Royer*
Chair: *El Houcine Bergou*

1 - Stochastic Three Points Method For Unconstrained Smooth Minimization
El Houcine Bergou

In this work, we consider the unconstrained minimization problem of a smooth function in a setting where only function evaluations are possible. We design a novel randomized derivative-free algorithm—the stochastic three points (STP) method—and analyze its iteration complexity. At each iteration, STP generates a random search direction according to a certain fixed probability law. Our assumptions on this law are very mild: roughly speaking, all laws which do not concentrate all measure on any halfspace passing through the origin will work. Although, our approach is designed to not explicitly use derivatives, it covers some first order methods. For instance, if the probability law is chosen to be the Dirac distribution concentrated on the sign of the gradient, then STP recovers the Signed Gradient Descent method. If the probability law is the uniform distribution on the coordinates of the gradient, then STP recovers the Randomized Coordinate Descent Method. The complexity of STP depends on the probability law via a simple characteristic closely related to the cosine measure which is used in the analysis of deterministic direct search (DDS) methods. Unlike in DDS, where $O(n)$ (n is the dimension of the problem) function evaluations must be performed in each iteration in the worst case, our method only requires two new function evaluations per iteration. Consequently, while the complexity of DDS depends quadratically on n, our method depends linearly on n.

2 - Zero Order Stochastic Weakly Convex Optimization
Vyacheslav Kungurtsev, Francesco Rinaldi

We consider stochastic weakly convex composite problems, however without the existence of a stochastic subgradient oracle. We present a derivative free algorithm that uses a two point approximation for computing a gradient estimate of the smoothed function. The method is guaranteed to be convergent at a similar rate as state of the art methods, however with a larger constant. We report some numerical results showing the effectiveness of the approach.

3 - A Nonmonotone Line Search Method with Finite-difference Gradient Approximations
Geovani Grapiglia

This talk describes a derivative-free method for unconstrained minimization of nonconvex smooth functions. Gradients are approximated by finite differences. The accuracy of the gradient approximations and the stepsizes that define the iterates are simultaneously adjusted using a general nonmonotone line search condition. For objective functions with Lipschitz continuous gradients, worst-case complexity bounds and global convergence results are presented. Preliminary numerical results are also reported.

■ MD-24

Monday, 14:30-16:00 - Virtual Room 24

Optimization with machine learning surrogate models

Stream: Global Optimization
Invited session
Chair: *Alexander Mitsos*
Chair: *Chryssa Kappatou*

1 - Expensive black-box optimization in process systems engineering
Antonio del Rio Chanona, Damien van de Berg, Thomas Savage, Panagiotis Petsagkourakis, Dongda Zhang, Nilay Shah

Most optimization problems in engineering can be formulated as expensive black box problems whose solutions are limited by the number of function evaluations. Frequently, engineers develop models that are differentiable or cheap to evaluate (or both) and resemble reality, so that they can be solved efficiently, and the solution can then be transferred to the real system. In the absence of gradient information or cheap-to-evaluate models one must resort to efficient optimization routines that rely only on function evaluations, creating a model can be itself considered part of the expensive black box optimization process. In this work, we investigate how different derivative-free optimization (DFO) algorithms can address different instances of problems in process engineering. In the algorithms side, we benchmark both model-based and direct-search DFO algorithms, which operate under different philosophies. On the problems side, the comparisons are made on two mathematical optimization problems and four chemical engineering applications: model-based design of experiments, flowsheet optimization, real-time optimization, and controller tuning. Various challenges are considered including constraint satisfaction, uncertainty, problem dimension, evaluation cost, etc. This work provides insights into the efficiency of data-driven solutions of optimization problems in the process systems domain in an effort to advance the digitalization of the chemical and process industries.

2 - Uncertainty measures and hierarchical acquisition functions for tree-based black-box optimization
Alexander Thebelt, Robert M. Lee, Nathan Sudermann-Merx, David Walz, Ruth Misener

Our recent work uses tree-based models, e.g., gradient-boosted trees, for black-box optimization. Tree models (i) give valuable information regarding feature importance, (ii) scale well for large amounts of data, (iii) are capable to handle various data types and (iv) have excellent local and global prediction capabilities depending on the number of trees and interaction depth used. Moreover, there are tight mixed-integer linear problem encodings of tree ensembles for effective usage as surrogate models inside Bayesian optimization loops. Off-the-shelf branch-and-bound solvers, e.g. Gurobi, can optimize these models to global optimality when combined in a lower confidence bound acquisition function and allow the integration of explicit input constraints. This presentation extends existing approaches by proposing a discrete uncertainty measure for search-space exploration that natively integrates into tree-based models. Moreover, we present a hierarchical acquisition function for usage in Bayesian optimization that explicitly leverages deterministic global solvers to simplify hyperparameter tuning. Finally, we evaluate tree-based models in a general multi-objective Bayesian optimization setting and present results based on commonly used benchmark problems.

3 - A data-driven inverse optimization approach to learning surrogate optimizers
Rishabh Gupta, Qi Zhang

Optimizing complex industrial systems in real-time settings is challenging since the optimization models for such systems are often large-scale and nonlinear, which prohibits their solution in a reasonable time.

A common strategy is to replace the original model with a surrogate model of reduced computational complexity. In this work, we introduce a data-driven inverse optimization (IO) approach for constructing surrogate optimizers, which are surrogate models that are trained to obtain (almost) the same optimal solutions as the original optimization models. In contrast to traditional machine learning methods, IO allows the incorporation of domain knowledge in the form of explicit constraints and tends to be more data-efficient. Moreover, it allows the resulting models to be inherently interpretable.

Our work assumes that a parameterized convex optimization model can be trained to obtain optimal solutions that are similar to what the original model generates. Here, the IO problem is to determine the model parameters that minimize the difference between the true optimal solutions and the solutions obtained from solving the resulting learned optimization model. We formulate the problem as a bilevel program and apply a penalty block coordinate descent method to solve the single-level KKT-based reformulation of the IO problem. We demonstrate the effectiveness of our method using several case studies including a nonlinear model predictive control example.

4 - Deterministic global optimization with surrogate models

Chryssa Kappatou, Dominik Bongartz, Jaromil Najman, Susanne Sass, Artur M. Schweidtmann, Alexander Mitsos

Within the broader scope of digitalization of the (bio)chemical industry, surrogate models are gaining increasing attention. Process optimization for monitoring and control of industrial processes necessitates models that are fast to evaluate. We present our work in this direction both from the software and algorithmic development side. We discuss our "Machine Learning Models for Optimization (MeLOn)" toolbox that enables integration of data-driven models to optimization problems. These problems are then solved in reduced space by our deterministic global optimization software "McCormick-based Algorithm for mixed-integer Nonlinear Global Optimization (MAiNGO)". Special emphasis is placed on theory and algorithm development for deterministic global dynamic optimization for a specific class of surrogate models, Hammerstein-Wiener models. We demonstrate advantages of our approaches using illustrative examples from process systems engineering applications. These advantages stem from the particular combination of utilizing the problem structure, the reduced-space formulation and the relaxation without auxiliary variables.

■ MD-25

Monday, 14:30-16:00 - Virtual Room 25

Stochastic Optimization for Robust Food-Water-Energy-Environmental Security Nexus Management

Stream: Stochastic and Robust Optimization

Invited session

Chair: *Tatiana Ermolieva*

Chair: *Yurii Ermoliev*

1 - Robust management of systemic risks and food-water-energy-environmental security in interacting natural and anthropogenic systems

Tatiana Ermolieva, Petr Havlik, Yurii Ermoliev, Taher Kahil, Elena Rovenskaya, Michael Obersteiner, Olena Borodina, Vasyl Gorbachuk, Pavel Knopov, Oleksandr Bogdanov

In the presentation we discuss critical issues related to the design of resilient and robust food, water, energy, environmental systems in the presence of interdependent systemic risks. We introduce the notions of systemic risks, security, resilience and robustness in FWEE systems. We emphasize the need for the two-stage preventive-adaptive stochastic optimization (STO) approaches enabling to design a robust portfolio of precautionary strategic and operational adaptive decisions making the interdependent systems flexible and robust with respect to risks of all kinds. We establish a connection between the robust quantile-based nonsmooth estimation problem in statistics and the two-stage nonsmooth STO problem of robust strategic-adaptive decision making. The coexistence of complementary strategic ex-ante and adaptive ex-post decisions induces systemic risk aversion in the form of Value-at-Risk quantile-based risk constraints. Using examples from research studies on integrated management of catastrophic dependent risks, integrated agricultural-water-energy nexus security, multidisciplinary water resource management we argue that coping with systemic risks can be addressed by solving a system of implicit probabilistic security equations. Selected numerical results from the studies illustrate that a robust combination of interdependent strategic and adaptive solutions presents qualitatively new policy recommendations contributing to the overall welfare increase.

2 - A two-stage stochastic optimization for a multidisciplinary water resource management problem in the presence of uncertainty and risks

Jose Pablo Ortiz Partida, Taher Kahil, Yoshihide Wada, Yurii Ermoliev, Tatiana Ermolieva, Samuel Sandoval Solis

The water resources systems analysis involves problems, which have to deal with multidisciplinary interacting water, agriculture and energy production and provision processes, multiple stakeholders, competing objectives, inherent uncertainties and interdependent risks. In this presentation, we formulate and discuss a novel two-stage strategic-adaptive stochastic optimization framework that maximizes regional economic benefits from water reservoir deliveries and integrates stochastic inflows into a water allocation system with multiple consumers, food-water-energy-environmental security targets, and various physical and institutional constraints. The model incorporates compound robust quantile-based performance indicators of various competing water users/systems, characterizing e.g. agriculture and energy production security, wetland and biodiversity preservation goals, flood protection and reservoir storage safety constraints. The performance indicators define the level of reliability, safety, resilience, and vulnerability required by each subsystem (water user), thus characterizing the risk of failures in the parts of the system and in the whole reservoir management system. The two-stage feature of the proposed nonsmooth STO model induces safety constraints on water supply known as chance/safety/probabilistic constraints. The model is applied to the case of the Big Bend Reach of the Rio Grande/Bravo transboundary river basin.

3 - Iterative solution procedure for nonsmooth nondifferentiable stochastic optimization: linking distributed models for food, water, energy security nexus management

Yurii Ermoliev, Anatoliy Zagorodniy, Vyacheslav Bogdanov, Tatiana Ermolieva, Petr Havlik, Elena Rovenskaya, Nadejda Komendantova, Michael Obersteiner

Detailed sectorial and regional models have traditionally been used for planning developments of respective sectors and regions. However, solutions that are optimal for a sub-system may turn out to be infeasible for the entire system. In this talk, we discuss a new modelling approach enabling the linkage of detailed distributed models of subsystems under joint resource constraints, uncertainty, systemic risks, and asymmetric information. The approach is based on a Stochastic Quasigradient (SQG) iterative solution procedure for nonsmooth nondifferentiable optimization problems. The models are linked in a decentralized fashion via a central planner (central "hub") without requiring the exact information about models' structure and data, i.e. in the conditions of asymmetric information and uncertainty. The sequential SQG solution procedure organizes an iterative computerized negotiation between sectorial (food, water, energy, environmental) systems (models) representing Intelligent Agents. The convergence of the procedure to the socially optimal solution is based on the results of nondifferentiable optimization providing a new type of machine learning algorithms. The linkage problem can be viewed as a general endogenous reinforced learning problem of how software agents (models) take decisions in order to maximize the "cumulative reward". The approach is illustrated by linking distributed agricultural, water and energy sector models for food-water-energy nexus security.

4 - A Financing Mechanism for Food Security in West Africa: A Stochastic Programming Approach
Matthias Wildemeersch, Debbora Leip, Elena Rovenskaya

Achieving food security is a key target of the Sustainable Development Goals, and is particularly challenging in West Africa due to its high population growth. Sustainable food systems that can deliver food security entail multiple dimensions of sustainability. In this context, the importance of agency has recently been recognized, referring to the capacity of individuals or communities to take decisions concerning production policies and governance of the food system. Agency requires farmers to maintain stable incomes, but increasing temperatures, droughts, and floods disempower farmers considerably. Here we propose a risk management scheme to ensure the food availability and guarantee stable incomes for farmers. The risk management scheme prescribes land allocation over different crops, and accounts for incurred costs when food imports are required or when payouts cannot be covered by the financing scheme. We use a chance-constrained optimization framework to study the feasibility of the risk management scheme, and provide solutions that are robust with respect to large crop yield variations. Our analysis provides insights into how regional cooperation can decrease necessary imports and government debt. Applying this framework to West Africa, our results demonstrate that risk pooling through regional cooperation is necessary to ensure food availability and the solvency of the financing mechanism.

■ MD-26

Monday, 14:30-16:00 - Virtual Room 26

Decision Analysis - Processes

Stream: Decision Analysis and Decision Analytics
Invited session
Chair: *Pavlos Delias*

1 - Reducing Sample Size Requirements by Extending Discrete Choice Experiments to Indifference Elicitation
Ambuj Kumar Sriwastava, Peter Reichert

Discrete choice experiments provide an excellent and unbiased estimation of preference model parameters. We demonstrate that by extending discrete choice questions for preference elicitation to the elicitation of preference indifference, we can achieve a reduction in the uncertainty of estimated value function parameters by about a factor of three. This is obtained at the cost of a higher elicitation effort for each question and involves extraction of preference information through indifference statements. Additionally, increased elicitation effort may also be required depending on the preference of the stakeholders or their ability to quantify the preference indifference point. We do a quantitative comparison between discrete choice experiments and indifference elicitation based on synthetically generated data and Bayesian parameter inference. In particular, we systematically analyze sample size requirements and achieved accuracy in parameter estimates and the effect of known deficits of the preference model used for the analysis. The elicitation of preference indifference opens new perspectives whenever the set of stakeholders from whom preferences have to be elicited is limited, e.g. in the case of preference elicitation from experts in environmental management or health economics. In such cases, the higher elicitation effort may be manageable and results in similar accuracy of results with about one-tenth of the sample size or higher accuracy for smaller sample sizes.

2 - Will Digital Coaching Be a DSS Redivivus Movement?
Christer Carlsson

When managers must take difficult decisions they tend to rely on experience and intuition more than analytical tools; managers feel personally responsible and know that a decision needs to be anchored in the conviction that it is the best (or only) alternative. The attitudinal core of the DSS movement since its beginnings has been (Peter Keen) "support, not replace (managers)" and "support (managers) to do a better job". This was originally done with algorithms managers could understand and use, and even work with through intuitive user interfaces. Things are more complex and difficult in the 2020's. Fast decision-making in almost real-time is a necessity in the digital economy ("the fast eat the slow"). Big data makes algorithms and DSS modelling impractical and decision-making too slow. Experience and intuition tend to replace analytical models to get quicker decisions or machine learning methods are introduced that are fast but cannot be understood nor used by managers; this makes them questionable as supports for managers to do a better job. We make the case that soft computing is a better (equally fast) approach than machine learning and show that soft computing used in digital coaching methods offers the means for managers to understand and use advanced 2020 tools. This is illustrated with a real options method used to decide on closing (or not closing) an ageing paper mill in the UK.

3 - A Strategic Tool for the evaluation of a company's Business Excellence & Competitiveness Level and the design of the appropriate Reorganization Plan
Nicos Bakalis

The paper presents a Strategic Tool for the Assessment of a Company's Business Excellence & Competitiveness Level based on Balanced Scorecard. The Tool consists of two parts, the "Basic Characteristics" part and the "Business Competencies" part. The first part refers to the basic characteristics for each company and contains five areas namely: annual turnover, number of employees, number of products / services, number of customers and existence of production. Each characteristic takes relevant values for different levels. The second part contains several business competency issues, that are divided in four categories, based on Balanced Scorecard, which are in turn divided in sub-categories in order to cover the most critical areas. The business competency issues are evaluated with a range of values indicating the low and the high and relatively showing the level of excellence of the company in each business competency. The score for each business competency issue is based on i) the value for each business competency ii) the value of the basic characteristic and iii) the correlation of the business competency with the basic characteristic. The Strategic Tool can be used as a "Quick Scan", that can be applied in companies of any sector and size, for the evaluation of a company's business excellence & competitiveness level and the identification of specific or broader areas for further and thorough business analysis or urgent reorganization actions.

■ MD-27

Monday, 14:30-16:00 - Virtual Room 27

Demand Management for Last-mile Logistics & Mobility

Stream: Analytics in Service Management
Invited session
Chair: *Claudius Steinhardt*

1 - On the concept of opportunity cost in integrated demand management and vehicle routing
David Fleckenstein, Vienna Klein, Robert Klein, Claudius Steinhardt

Demand control problems in the field of vehicle routing are characterized by a stream of customers arriving dynamically over a booking horizon and requesting logistical services which are fulfilled by a given fleet of vehicles. Customers commonly have heterogeneous preferences for different fulfillment options. Hence, demand management methods can be applied to control the booking process with the aim of maximizing total profit. The quality of demand management decisions depends to a large extent on an accurate estimation of opportunity cost. In the context of integrated demand management and vehicle routing, this term denotes the monetary value of the fulfillment resources that are expended as a consequence of selling a certain logistical service to an arriving customer. As the concept of opportunity cost is such an essential component of any demand management approach, we formalize its definition specifically for vehicle routing applications. Drawing on a prototypical model, we investigate and illustrate properties of opportunity cost. Finally, we discuss implications for solution approaches which are proposed in the recent academic literature on various problem settings.

2 - Multi-trip vehicle routing with delivery modes: A demand management opportunity for CEP services
Lukas Janinhoff, Robert Klein

To tackle the last mile of parcel delivery more efficiently, service providers offer more and more modes of delivery as alternatives to the traditional and often cost-intensive home delivery service. Parcel lockers and pick-up stations may be utilized to reduce the number of stops; crowdshipping and subcontracting may similarly help in avoiding costly detours. In order to design smart delivery networks, service providers have to evaluate different business models. In this context, a multi-trip vehicle routing problem with delivery modes and location-dependent costs arises. We show a corresponding model and solve it heuristically using adaptive large neighborhood search. We apply both well-known operators from the literature adapted to this context as well as new operators explicitly developed for this problem. Examining large, real-life instances from a major German parcel service, we determine the potentials and benefits of different delivery modes. Furthermore, we discuss possible consequences for demand management on a strategic level.

3 - Dynamic demand management and online routing for same-day delivery
Vienna Klein, Claudius Steinhardt

With the ongoing growth of e-retail sales and an increase of customer expectations, offering same-day delivery options has gained high importance for providers, in order to stay competitive. Typically in same-day delivery, customers purchase online and expect to receive their order within very narrow delivery spans which leads to substantial operational challenges for the providers. One major challenge is to consolidate a sufficient amount of customer orders to delivery tours to reach profitable delivery operations. We tackle this problem by combining a revenue management approach with an online tour planning approach for same-day delivery to steer customer choice towards efficient routing operations. We therefore develop a sample-scenario based value approximation method, that is based on an explicit anticipative online routing heuristic. The approach does not require extensive offline learning and is scalable to realistic sized instances with multiple vehicles.

4 - Modeling Supply and Demand Matching for Free-Floating Shared Mobility System Optimization
Matthias Soppert, Claudius Steinhardt, Christian Müller, Jochen Gönsch, Prasanna Bhogale

Shared mobility systems have become an essential mode of transportation in the inner-city mobility landscape. However, their operational control, for example by relocation or pricing, remains a challenge, because the spatio-temporal distribution of available and demanded vehicles is constantly changing. A central component in optimization models for shared mobility systems concerns the realization of rentals as a function of available vehicles and arriving customers, i.e. the formalization how supply and demand match. Despite the fundamental differences between station-based and free-floating shared mobility systems, their optimization models usually base on identical assumptions regarding this matching. This simplification can result in substantial modeling errors along with suboptimal decision-making, as it became apparent to us in a close collaboration with Share Now, Europe's largest free-floating car sharing provider. In our work, we develop novel analytical matching models that incorporate important influencing factors specifically relevant for free-floating systems, such as the customer behavior to have a maximum willingness-to-walk and the size of a zone. Computational studies demonstrate that the novel matching models predict rentals more accurately and in a pricing case study based on real-world data, we demonstrate that the more accurate matching modeling also allows to derive better pricing decisions that increase revenues and profits significantly.

■ MD-28

Monday, 14:30-16:00 - Virtual Room 28

Data Science and Analytics - Applications in Marketing

Stream: Data Science and Analytics (contributed)
Contributed session
Chair: *Alicia Zanfrillo*

1 - An aspect-based sentiment analysis system to analyze customers' reviews from food and beverage opinion and review webpages
Anastasios Liapakis, Theodore Tsiligiridis, Constantine Yialouris, Constantina Kostopoulou

Nowadays, more and more companies use social media networking to attract more customers. This modifies consumers' attitudes, but companies cannot detect these modifications due to the big volume and the diversity of the produced information. In the case of the Greek Food and Beverage (F&B) industry, the use of social media networks is very high for multinational and large companies. The purpose of this paper is to analyze 2.645 customers' reviews (written in the Greek language) of some big companies in the Greek Food and Beverage industry as they are uploaded in opinion and review sites and especially on TripAdvisor. The mining of customers' reviews covers a two-year period and the evaluated functions are the quality of food, the customer service, the image of the company, the pricing, and the quantity of food. The sentiment analysis in an aspect-level using the lexicon-based technique should approach methodologically the problem by identifying not only the relevant information but also the expressions and phrases the evaluators use over the Internet. The extracted keywords and phrases from the customers' reviews are used to form the corresponding dictionaries of the evaluated functions and to proceed in the sentiment classification. Lastly, the method is tested in an annotated dataset of customers' reviews and, overall, the findings are expected to contribute towards the design and implementation issues of a sentiment lexicon particularly devoted to the industry.

2 - Analysis of Customer Response Patterns in Direct Marketing Campaigns: A Gibbs Sampling Approach
Young H. Chun

Based on the customer response records in a direct marketing campaign, we can predict response patterns such as the ultimate response rate and the response speed. Many curve-fitting methods have been proposed to describe and estimate the cumulative number of responses over time. In this paper, we propose a probabilistic model with two parameters. We use a Bayesian method to estimate the two unknown parameters, and illustrate our Bayesian method with empirical data. Unlike other conventional methods, our Bayesian model effectively considers the prior information about the unknown parameters as well as the sample data when it becomes available over time. Another advantage of our Bayesian model is that we can find confidence intervals, as well as point estimates, of unknown parameters and test hypotheses under various loss functions.

3 - Configuration of the glocal responsibility profile with unsupervised learning techniques for value creation
Alicia Zanfrillo, Rebeca Yuan, Ezequiel Gribaudo, Victoria Leuci, Carola Sosa

Faced with the challenges of the Sustainable Development Goals and the global alerts for food safety, socially responsible behavior becomes a source of attraction for suppliers and customers, making it a strategic resource for organizations. The current models of Corporate Social Responsibility (CSR) redefine the hierarchy of factors and its components, innovating in the incorporation of glocal responsibilities, which include the environment, socio-cultural issues, technology users and political nature, resulting in a subject of interest both to comply with the demands of the environment and to identify competitive advantages. The present study consists of characterizing the new glocal factor of CSR of the international model in its four dimensions, for the salting and processing plants of Buenos Aires anchovy (Engraulis Anchoita) in the city of Mar del Plata today. The work proposes to define indicators to quantify the communication of the companies about the new factor and the comparison between the organizations that make up the fishery, making their actions visible through the multiple correspondence analysis. Different asymmetries are observed, particularly in the technological and political dimensions of the communication of CSR practice, which account for a slow penetration of Industry 4.0.

4 - Liner health prediction using intelligent two-stage machine learning models
Sourav Bhunia, Shoban Babu Balasubramani, Tuhin Kanti Mondal

Crushers are a crucial equipment for pre-processing of lime stones in cement industries. Due to high-impact process, the liners of the crushers often suffer from ware and tares. Usually, these crusher liners are monitored on need basis and, replaced once the liner's performance is not in acceptable range. An intelligent predictive model could help the maintenance engineers to predict the health upfront and plan the maintenance activities appropriately.

In our approach, we have developed a two-stage machine learning model to predict the health of the crusher liners and its next replacement time. Challenged by limitation of crusher inspection information, at first, a weighted prediction model was generated to estimate crusher ware & tare using uncontrollable variables. Next, in actual health prediction model, results of first estimation model was fed, and a final ensemble model was developed.

Result of our analysis showed that our model performed around 20% more accurate compared to existing model used by clients. Also, the model performance showed significant improvement on recent data compared to older data proving that the health of crusher liner has been successfully incorporated in model. This model can equip the operator to get an idea of the changes in liner wear at any instant, leading to the manual tuning of the controllable parameters of the plant within a certain acceptable limit and thus extending the remaining useful life of the roller liners.

■ MD-29

Monday, 14:30-16:00 - Virtual Room 29

Dynamics and Games 1

Stream: Dynamics and Games
Invited session
Chair: *Alberto Pinto*

1 - A Search Game in Discrete Locations
Jake Clarkson, Kyle Lin, Kevin Glazebrook

Consider a two-person zero-sum search game between a hider and a searcher. The hider chooses where to hide among n discrete locations, and the searcher successively visits individual locations until finding the hider. A search at a location takes a known location-dependent search time and will find the hider—if hidden there—independently with a known, location-dependent detection probability. The hider aims to maximize the expected length of the search, while the searcher aims to minimize it.

Due to the search game being semi infinite and hence difficult to solve, most work in the current literature is limited to two locations or locations searched in unit time. Using novel proof techniques, we develop a comprehensive theory for the fully-general search game by extending much of the existing work and uncovering new properties along the way.

We prove the existence of the optimal strategy for each player. In particular, the hider's optimal mixed strategy hides in each location with a nonzero probability, and the searcher's optimal mixed strategy can be constructed with up to n simple search sequences. We also develop an algorithm to compute an optimal strategy for each player, and we investigate numerically how the optimal hiding strategy compares with the simple hiding strategy that gives the searcher no preference over any location at the beginning of the search.

2 - Playing Stackelberg Security Games in Perfect Formulations
Pamela Alejandra Bustamante Faúndez

Protecting critical infrastructure from intentional damage requires considering the behavior of attackers. This problem can be formulated as a Stackelberg security game. Here, a "defender" must protect specific targets with limited resources, maximizing its expected utility and considering that a second player, called "attacker", responds optimally. One of the challenges in solving Stackelberg games in real applications is the size of the problem. In general, finding optimal strategies for Stackelberg games is NP-Hard. Our primary goal is to establish the connections between the algorithmic implications of the polyhedral structure of the defender's strategy set and the development and implementation of efficient solution methods and algorithms on a large scale. The first point relates to analyzing the difficulty of solving a Stackelberg security game and the defender's strategy space structure. To this end, we study security games with defender strategies that can be modeled as perfect formulations, such as b-matchings and schedules of size 2. The second point implies evaluating efficient solution methods. In this context, we use formulations that either describe the set of pure strategies explicitly or describe the space through marginal probabilities. We develop branch&price and branch&cut schemes to deal with large instances, and we study several algorithmic enhancements as stabilization methods and heuristics to get good initial feasible solutions.

3 - Horizontal differentiation in a Hotelling Network with uncertainty on costs.
João Almeida, Alberto Pinto

We develop a theoretical framework to study the location-price competition under uncertainty of firms' production costs. Firms compete in a two-stage Hotelling- type network game, with linear transportation costs. We show the existence of a Bayesian-Nash equilibrium price if, and only if, some explicit conditions on the ex- pected production costs and on the network structure hold. Furthermore, we prove that the local optimal location of the firms are at the nodes of the network.

■ MD-30

Monday, 14:30-16:00 - Virtual Room 30

System Dynamics Modeling and Simulation - Session 2

Stream: System Dynamics Modeling and Simulation
Invited session
Chair: *Markus Schwaninger*
Chair: *Camilo Olaya*

1 - Inadequate groundwater management and unsustainable agriculture: The case of pistachio production in Iran
Ali Akhavan, Paulo Goncalves

Benefiting from historically favorable conditions, pistachio producers in Rafsanjan, Iran, have flourished, with pistachio orchards and production growing dramatically since the 1970s. Today however, the enormous increase in water consumption associated with pistachio production, has severely depleted groundwater aquifers, causing widespread water shortages in the region. In this work, we develop a comprehensive system dynamics model, combining the agronomic, economic, hydrologic, and behavioral aspects to analyze the long-term implications of pistachio production. Our research contributes to the literature of agricultural water management in three significant ways (1) it provides a validated and quantitative model exploring pistachio farming for a region, (2) it explicitly captures behavioral decision rules associated with orchard growth and production investment, and (3) addresses a natural common pool resources problem with very long-time horizons. We consider several policies aimed at addressing the problem (e.g., water transfers, drip irrigation, financial subsidies, income tax, water pricing, and land purchasing). Our results suggest that policies that increase the effectiveness and efficiency of production, albeit preferred by farmers, leads to better-before-worse results, depleting groundwater storage in the long-term. Insights from the model can help policymakers have a better understanding of the unintended consequences of their policies.

2 - Exploring the effects of infrastructure policies on availability and accessibility of nutritious food in Brazilian favelas: A System Dynamics approach
Thiago Piovan, Vinicius Picanco Rodrigues, André Duarte

The Food and Agriculture Organization has estimated that about 815 million people globally suffer from chronic undernourishment with the majority living in low-income countries. This situation has been aggravated by the COVID-19 pandemic. In this context São Paulo displays major challenges regarding public policies for food and nutritional security. While some areas of the city suffer from deprivation and scarcity of healthy food sources ("food deserts"), other areas have disproportionately high availability of unhealthy foods - i.e., rich in calories, low in nutrients ("food swamps"). Several studies have contributed to illustrating food environments in large Brazilian cities and its infrastructural elements. Yet practically no studies examine vulnerable communities in favelas (slums) characterized by precarious settlements that arise from spontaneous urban occupations carried out in a disorderly manner. We aim at exploring the effects of public urban infrastructure policies on the availability and accessibility of nutritious food in São Paulo favelas. By developing a System Dynamics approach it is possible to capture the elements of the food system in favelas and provide an endogenous view on how the food environment can evolve to better serve underprivileged communities. Simulation results can support the design of public policies targeted at enhancing availability and access to nutritious food in favelas via precise interventions in urban infrastructure.

3 - Analyses of decontamination scenarios of an urban object
Anna Selivanova, Igor Krejci

Using the System Dynamics Approach, decontamination scenarios of a selected urban object were created. Decontamination scenarios anticipated deposition of chosen artificial radionuclides on surfaces of the urban object after a nuclear or radiation accident. Hence, relevant countermeasures were connected into decontamination sequences (scenarios). Conditions in the Czech Republic were taken into account within the scenario modelling. Within simulations of proposed scenarios, costs of decontamination were obtained. Calculated costs were subsequently compared with clean-up costs after the Fukushima Daiichi Accident or the Chernobyl disaster. Obtained results could be used as resource materials for the decision-making process within remediation planning.

■ MD-31
Monday, 14:30-16:00 - Virtual Room 31

Approximation Approaches for Multiobjective Optimization

Stream: Multiobjective Optimization
Invited session
Chair: *Lakmali Weerasena*

1 - An approximation algorithm for the generalized multi-objective set cover problem
Lakmali Weerasena

The multi-objective Set covering optimization problems (MOSCPs) are popular since their extensive applications in the real world. This study addresses the generalized multi-objective SCP (GMOSCP) which is obtained the generalizing the coverage constraint of the MOSCP. A mathematically-driven heuristic algorithm proposed based on a branching approach of the feasible region to approximate the Pareto set of the GMOSCP. The algorithm consists of a number of components including initial stage, constructive stage, and improvement stage. Each of these components contributes significantly to the performance of the algorithm. We propose multiple cost-efficient rules in the constructive stage and investigate the effect of them approximating the Pareto set. We have used a diverse set of GMOSCP instances with different parameter settings for the computational experiments.

2 - Parallel Computing Techniques for the Multi-Objective Set Cover Problem
Ryan Marshall, Lakmali Weerasena

The multi-objective set covering problem (MOSCP) appears in many different real-world applications. We implemented a meta-solver in C++ that introduces shared-memory concurrency using OpenMP. It incorporates a commonly-used Mixed Integer Problem (MIP) solver to find initial solutions with a linear programming (LP) solver that enumerates possible solutions over a tree of subproblems using a branch-and-bound approach. Adhering to a finite cutoff value, solutions are ordered as they are passed back up the tree to produce the set of Pareto fronts. In this paper, we expand our experimental results from a prior work by observing the performance of an implementation using different thread-to-resource mapping strategies combined with a variable search procedure, and report the combinations that produce the fastest times to solution.

3 - Near-optimal algorithms for Pareto frontier approximation
Erik Diessel

Many multiobjective optimization methods approximate a Pareto frontier by a set of points in objective space. The efficiency of these methods can be analyzed by comparing the number of points the algorithm needs to achieve a given approximation quality with the number of points needed at the minimum for this on the given instance, which we call the Pareto complexity. Only for a small number of approaches it has been established that their number of generated points is within a small factor of the Pareto complexity. For example algorithms for two and three objectives by Vassilvitskii and Yannakakis generate a number of points within a constant factor of the Pareto complexity while they show that for higher dimensions this becomes NP-hard.

In this talk we provide a new class of Pareto frontier approximation algorithms usable for any number of objectives. We establish that our algorithm converges to any desired approximation quality and the number of generated points is bounded within a small polylogarithmic factor of the Pareto complexity at this approximation quality. Our measure for the approximation quality is related to the hypervolume. We show that the number of computations by the algorithm is bounded by a polynomial in the number of generated points, for a fixed number of objectives. We illustrate how the used auxilary problem of finding new points which provide maximal improvement can be formulated in the same problem class as the original multicriteria problem.

4 - How to know it is 'the one'? A comparative study to select the most suitable solution among the Pareto-optimal set of solutions
Elif Goksu Ozturk, Ana Maria Rodrigues, José Soeiro Ferreira, Cristina Oliveira

Multi-objective optimization methods search for a feasible set of solutions by evaluating several objectives simultaneously. However, selecting a solution among multiple trade-off solutions located in the Pareto Frontier requires further effort. In this work, we propose a new method, based on the Analytical Hierarchy Process, to choose the most suitable solution among several trade-off solutions by considering the decision-maker's preferences. In this method, trade-off solutions are classified regarding their superiority, allowing to compose the pairwise comparison matrices among the trade-off solutions for each objective. Finally, the most convenient solution is provided regarding the preferences of the decision-maker. Besides being easily implemented, this method is useful to select a trade-off solution regardless of the number of objectives. We tested the proposed method on sectorization problems using our instances considering three objectives: equilibrium, compactness, and contiguity. The Non-dominated Sorting Genetic Algorithm-II is used to obtain Pareto-frontier solutions. According to the experiments, the proposed method rapidly selects a suitable solution. We evaluated the method's credibility by comparing the similarity between the solution selected and the solution obtained by a weighted composite single objective function. We observed a notable similarity between the two solutions.

■ MD-32
Monday, 14:30-16:00 - Virtual Room 32

Fair and explainable models 2

Stream: Multiple Criteria Decision Analysis
Invited session
Chair: *Luis Galarraga*
Chair: *Miguel Couceiro*

1 - Making Machine Learning Explanations Truthful and Intelligible
Kacper Sokol

Predictive models come with a myriad of well-defined performance metrics that guide us through their development, validation and deployment. While the multiplicity of these measurements poses challenges in itself, the lack of agreed-upon evaluation criteria in machine learning explainability creates even more fundamental issues. For one, transparency of predictive algorithms tends to be elusive and notoriously difficult to measure. Without universal and objective interpretability metrics, our evaluation of such systems may be subject to personal preferences exhibited by "I know it when I see it" attitude and human cognitive biases, for example, the illusory truth effect and the confirmation bias. Resorting to user studies – considered the field's gold standard – may not be of much help either when the assumptions of test and deployment environments are misaligned.

Shall we take machine learning explanations at their face value? What to do when we are shown multiple, possibly conflicting, explanations? What prior (technical) knowledge do we need to appreciate their insights and limitations? With all of these questions and not many definitive answers, how do we go beyond naive compliance with legal frameworks such as the GDPR? In this talk I will show how to identify obscure assumptions and overcome inherent limitations of black-box explainers to generate truthful and intelligible insights that can be harnessed to satisfy our scientific curiosity and create business value.

2 - Exploiting Auto-Encoders for Explaining Black Box Classifiers
Riccardo Guidotti, Anna Monreale

Artificial Intelligence (AI) has nowadays a tremendous socio-economic impact and a pervasive adoption in every field of modern society. Many applications in different fields, such as credit score assessment, medical diagnosis, etc., are based on AI systems. Unfortunately, these systems often reach their impressive performance through obscure machine learning models that "hide" the logic of their internal decision processes to humans. For this reason, these models are called black boxes. The missing interpretability of black boxes is a limitation to AI adoption in socially sensitive contexts. As a consequence, the research in eXplainable AI (XAI) has recently caught much attention. A promising line of research in XAI exploits auto-encoders for explaining black box classifiers working on non-tabular data (images, time series, etc.). The ability of autoencoders to compress any data in a low-dimensional tabular representation, and then reconstruct it with negligible loss, provides the great opportunity to work in the latent space for the extraction of meaningful explanations, for example, through the generation of new synthetic samples that can be fed to a black-box to understand where its decision boundary lies. We discuss recent XAI solutions based on autoencoders that enable the extraction of meaningful explanations composed by factual and counterfactual rules, and by exemplars and counter-exemplars, offering a deep understanding of the local decision of the black box.

3 - Explainable Time Series Classification
Yichang Wang

In this talk, we will study different existing methods that can be used to explain decisions taken by time series classification models. We argue that, in the case of time series, the best explanations should take the form of sub-series (also called shapelets) since it is " pattern language " familiar to a time series user.

We review state-of-the-art classification methods that can jointly learn a shapelet-based representation of the series in the dataset and classify the series according to this representation. However, although the learned shapelets are discriminative, they are not always similar to pieces of a real series in the dataset. This makes them difficult to use to explain the classifier's decision. We make use of a simple convolutional network to tackle the time series classification task and we introduce an adversarial regularization to constrain the model to learn meaningful shapelets.

Our classification results, on many univariate time series benchmark datasets, are comparable with the results obtained by state-of-the-art shapelet-based classification algorithms. However, we show, by comparing to other black box explanation methods that our adversarially regularized method learns shapelets that are, by design, better suited to explain decisions.

■ MD-33
Monday, 14:30-16:00 - Virtual Room 33

MCDA for sustainability, resilience and risk assessment

Stream: Multiple Criteria Decision Analysis
Invited session
Chair: *Marco Cinelli*

1 - Sustainable Sourcing in the Apparel Industry with Unknown Implicit Value Function
Mirel Yavuz, Charles Corbett

The apparel industry accounts for substantial environmental impacts worldwide in categories including global warming potential, water use, abiotic resource depletion and others. Improving the performance in one category can result in worse performance in others. Firms such as Nike, Patagonia and many others, who pay attention to sustainability, face difficult choices during material and supplier selection with no well-defined guidelines on how to make trade-offs between different environmental impact categories. In this work, we consider sustainable sourcing in the apparel industry, where the economic and environmental preferences of the decision maker are based on an unknown implicit value function. We propose an interactive optimization approach that asks pairwise comparison questions to the decision maker to determine the sourcing mix that is most aligned with her preferences. We account for the cognitive load on the decision maker and aim to ask as few questions as possible that are also relatively easy to answer. We numerically test our approach using realistic data based on the Sustainable Apparel Coalition's Higg Material Sustainability Index (MSI) with three to four criteria: cost, global warming potential, water use and fossil fuel use.

2 - A sustainable inventory model for a perishable product with multiple transportation modes
Mozhgan Assari, Sena Eruguz, Wout Dullaert, Reinout Heijungs

With the increased attention for global warming, sustainability throughout supply chains has gained more interest in industry and academia. To reduce greenhouse gasses (GHG) emission, governments also set new regulations for the companies to integrate sustainability in their business strategies. Therefore, both the cost and environmental impacts of main logistics activities such as production, storage and transportation should be considered in supply chain decision-making. Most research on inventory models only focuses on the total cost and ignores the environmental impact. There are a few papers considering both cost and environmental impact, but since they ignore perishability and transportation lead time, they do not capture the key sustainability trade-offs. Our paper integrates the environmental impacts of production, inventory, transport, and perishability. It develops a sustainable inventory model using carbon tax policy for a perishable product with deterministic demand. Moreover, it considers multiple transportation modes with different lead times, costs, and emissions. We use numerical examples to assess the total cost and environmental impact of different transportation modes. Next, we show that taking non-zero lead time into account leads to more sustainable and efficient solutions as compared to using existing models which neglect the lead time. Finally, sensitivity analysis is done to show the impact of some key parameters on the total cost and carbon emissions.

3 - Measuring Smart City Performance: A Multiple Criteria Decision Analysis Approach
Pantelis Sotirelis, Panagiotis Nakopoulos, Evangelos Grigoroudis

Over the past years, rapid urbanization rates have negatively affected the environmental and socioeconomic sustainability. The concept of "smart cities" is commonly identified as a solution to reduce sustainability challenges and to improve quality of life, thus the effective assessment of cities' smartness is a highly important topic. This paper suggests a framework that defines and measures smart city performance. It incorporates a set of several smart city indicators classified under six main smart dimensions, i.e., economy, mobility, environment, people, living, and governance. The PROMETHE II method is applied to assess the smart performance of 17 cities worldwide. In addition, sensitivity analyses in respect to the basic parameters of the method are implemented, validating the robustness of the results. The PROMETHE II rankings are then compared with those of other well-established frameworks, while valuable insights are obtained.

4 - A Multicriteria Decision Aid Methodology for Classifying Countries based on their energy performance: The World Energy Trilemma Case
Efstratios Kartsonakis, Evangelos Grigoroudis, Constantin Zopounidis

Climate change has led countries to alter their energy policies by paving a way for greener environment and enhancing their performance regarding their energy sustainability. Energy sustainability is one of the most crucial aspects of modern economies as it is depended on technological, environmental, and socio-economic issues. In this context multiple studies have focused their research on the development of energy systems that will be able to assist countries to keep track of their energy policies. Most of the studies have adopted multiple criteria decision analysis (MCDA) techniques due to the high complexity of the problem and the necessity to consider multiple and competitive indicators. The main aim of this study is to introduce a framework that measures and classifies a set of countries regarding their energy sustainability. It uses multiple indicators based on the World Trilemma Index and evaluates 118 countries by using the UTADIS method (UTilités Additives DIScriminantes). The results indicate how the examined indicators affect a country's energy performance and offer a new perspective regarding the design of new energy policies. Finally, the overall scores (global utilities) of the counties can be used as a novel index that may help countries to compare their performance with others that belong to the same class.

■ MD-34
Monday, 14:30-16:00 - Virtual Room 34

Applied Combinatorial Optimization

Stream: Combinatorial Optimization
Invited session
Chair: *Dominique de Werra*

1 - Linear lexicographic optimization and preferential bidding system
Nour ElHouda Tellache, Frédéric Meunier, Axel Parmentier

When building the schedules of their crew members, airlines have to cover all pairings and satisfy as well as possible the preferences of the crews. With the preferential bidding system, the crew members bid on the various activities and the system aims at finding the schedules that maximize the scores of the crews in a lexicographic way: the most senior is served first, then the second one, etc. A sequential approach to solve this problem is natural, and actually quite common: the problem is first solved with the bids of the most senior crew member in the objective function; then it is solved with those of the second most senior without decreasing the score of the most senior, and so on. Each step often involves column generation, requires solving an integer program, and usually takes into account the possible schedules of the less senior crew members in an approximate way, which might compel to time-consuming backtrackings. It is commonly admitted that such a sequential approach is somehow dictated by the nature of the problem. In this work, we show that this belief is actually not completely correct by proposing a method that first solves the continuous relaxation of the full problem (with its lexicographic objective) via column generation and then finishes with a single call to an IP solver. The pricing subproblem of the column generation consists in solving a lexicographic resource-constrained shortest path problem. Experiments show the efficiency of the approach.

2 - Efficient Leader Election in Wireless Sensor and IoT Networks
Reinhardt Euler, Ahcene Bounceur, Madani Bezoui, Mohammad Hammoudeh, Loic Lagadec, Abdelkader Laouid

Leader Election is a classical problem in distributed systems in which one of the processes is chosen to organize a common task. In wireless sensor networks a leader is often a node of minimum or maximum value such as its identifier, remaining battery life, level of trust or its x- or y-coordinate in the plane which allows to start an algorithm to find the network's boundary. We present and discuss the Dominating Tree Routing algorithm (DoTRo) which starts from local leaders, running as a root, the process of flooding (distributed BFS) to determine a spanning tree of the underlying graph. During this process, the value of the local leader will be routed and if two trees meet, the tree routing the better value will continue its process while the other one will stop. The root of the final spanning tree will be the leader of the network. We conclude with a performance evaluation and some applications.

3 - On a Conjecture for the University Timetabling Problem
Wieslaw Kubiak

The University timetabling model has been introduced by Asratian and de Werra to add new features to the well-known class-teacher timetabling model. In the University timetabling in addition to lectures given by a single teacher to a single class, there are some lectures given by a single teacher to a group of classes simultaneously. One looks for a minimum number of periods in which to complete all lectures without conflicts. The problem is NP-hard in the strong sense even if the number of groups is three, but it is polynomially solvable for two groups. In the latter case, it has been conjectured that the minimum number of periods in which to complete all lectures without conflicts can be obtained by rounding up the optimal value of an LP-relaxation. The LP-relaxation permits fractions of periods in feasible solutions. We prove that this conjecture holds.

4 - Nature inspired approaches for dynamically changing optimization problems
Frédéric Guinand

During its long history, Earth has seen important environmental changes with periods of important vulcano activities, meteorits impacts, collisions of continents, major climate changes, geomagnetic reversals, ice ages, etc. But, along geological ages, Earth has also seen the development of a considerable amount of living systems composed of myriads of entities interacting with each other within a continuously changing environment. And, despite oftenly very harsh environmental conditions, life managed to adapt. Adaptation is usually studied/examined at the individual level, but we may question the role of the networked and decentralized characteristics of living systems in this adaptation. Observation of current ecosystems gives us some clues for answering this question, but gives also some ideas in the design of methods for solving problems focusing first on robustness rather than optimization. We illustrate our point with some example inspired by ant colonies and some theories from biology and related fields.

■ MD-35

Monday, 14:30-16:00 - Virtual Room 35

Combinatorial Optimization in Health and Social Care I

Stream: Combinatorial Optimization
Invited session
Chair: *Helena Ramalhinho Lourenco*

1 - Solving the single-day home health care problem with route interdependencies
Alberto Kummer, Olinto Araújo, Luciana Buriol, Mauricio Resende

The home health care problem consists of scheduling visits to home patients by a set of health professionals while following a series of requirements from patients, caregivers, and work regulations. Most of the problem's variations consist of a routing problem with time-windows. Some authors also consider additional constraints to model some requirements from the problem scope. One of the most frequent aspects of the problem is the multiple health specialties required by the patients. A patient can require simultaneous attendance by two caregivers for coping with, e.g., the services of "bathing" and "bandage replacement." Similarly, some services may require a separation between the two service types, e.g., an "insulin shot" before serving a "meal." The literature also approaches problems with various planning horizons. Frequently the problem consists of a single day of planning. Still, the number of publications approaching problems of several days is becoming more frequent. Yet, the single-day variations of the problem still relevant, and there is still have room for improvement of the solution methods. Very recently, we successfully applied a biased random key genetic algorithm to solve the single-day problem. Such an approach proved to be more effective than local search-operators tailored for the problem with route interdependencies.

2 - Synchronization and continuity of care concerns in home social care planning - a case study
Ana Raquel de Aguiar, Maria Isabel Gomes, Tania Ramos

Aging and the increasing prevalence of chronic diseases are accelerating public health expenditure. A path to mitigate these expenditures is to adequality coordinate health and social systems, bringing patients home earlier which reduces the needs for specialized health resources (as hospitalization demands). Home social care organizations provide social services allowing patients to recover or stay at home. The problem complexity (e.g. several visits a day, different autonomy levels) and the inexistence of proper Decision Support Systems for home social service planning lead to inefficient caregivers' daily routing and scheduling plans. This work is motivated by a real case. The organization provides care to patients requiring visits by either one or two caregivers, the latter with the majority of requests. Currently, the organization builds two kinds of routes: one for patients requiring one caregiver (semi-dependent patients), and another for a team of two caregivers (bedridden patients). To improve route planning quality, a MIP model is proposed which accounts for care continuity and caregiver synchronization, allowing teams of one caregiver to join and visit bedridden patients. The model decides upon the number of teams of each type (single or double) and minimizes service and travel times. Results propose a solution with one less caregiver than in the current planning, evidencing capacity to provide services to patients currently on the waiting list.

3 - Hybrid VNS and MIP for the Beam Angle Optimization Problem in Radiation Therapy
Maicholl Gutierrez, Guillermo Cabrera-Guerrero, Carolina Lagos

Intensity Modulated Radiation Therapy (IMRT) is one of the most widely used radiation therapy techniques to treat cancer. The main goal is to obtain a treatment plan that eliminates cancer cells from the tumour and, at the same time, damages the organs at risk (OAR) around the tumour as little as possible. Heuristic Beam Angle Optimization (BAO) techniques try to combine both exploration and exploitation moves to seek for the best beam angle configuration (BAC) to irradiate from. In this work, we propose a Variable Neighbourhood Search algorithm that explores the search space using a relaxed Mixed-Integer Programming model as an exploration strategy, which allows us to evaluate all possible combinations of several beam angles at the same iteration. This movement allows us to find better results in a competitive time. We try our approach on a set of clinical prostate cases obtaining quite promising results.

4 - Multiobjective optimization in district heating systems: the case of Berlin
Christine Tawfik, Jan-Patrick Clarner, Thorsten Koch, Janina Zittel

Owing to their flexibility and efficiency potentials, district heating systems play a crucial role in the sustainable development of urban energy production. Nevertheless, the operational design of the target portfolios entails a non-trivial trade-off between the environmental and energetic benefits, on one hand, and the economic expenses, on the other. In this work, we consider a concrete problem represented by a multi-objective, multi-period optimization model of energy production planning on a district heating grid in Berlin. Direct fuel-to-heat conversion technologies, renewable resources, as well as combined heat and power plants are included in the model. The currently used state-of-the-art portfolio planning tool is only able to optimize the annual economic costs with respect to a restricted horizon due to the huge problem size. We broaden this scope to include the CO2 emissions and the primary energy factor within the optimization objectives. We develop a solution algorithm based on the classical Epsilon-constraint method in order to approximate the Pareto frontier and provide the decision maker with a range of efficient solutions to select from according to the actual business and societal interests. To overcome the computational complexity, we apply enhancement techniques to dynamically adapt the objective bounds in the interest of avoiding redundant or weakly-dominated solutions. A real-world case study is considered to demonstrate the proposed method.

■ MD-36

Monday, 14:30-16:00 - Virtual Room 36

EEPA 2

Stream: EURO Excellence in Practice Award
Award Competition session
Chair: *John Poppelaars*

1 - Sustainable and efficient logistics: How optimization transformed Italmondo's cargo loading operations
Alessio Trivella, Mikele Gajda, Paolo Giannotti, Renata Mansini, David Pisinger

Logistics companies around the world face increasing pressure, exacerbated by the Covid-19 pandemic, to handle larger volumes of freight even faster. At the same time, growing environmental concerns push these companies to meet climate targets by reducing a typically high carbon footprint. Therefore, pursuing strategies to operate more efficiently and sustainably is a must in modern logistics.

In this project, we have successfully developed Operations Research methods at Italmondo Spa, a multinational logistics and transportation company that loads and ships hundreds of trucks every day. We have tackled the key operational process of loading a truck fleet, previously performed manually, by solving a complex variant of the container loading problem, which: (i) is multi-objective, (ii) jointly complies with several practical constraints, some of which only sparsely studied in the literature, and (iii) is subject to strict industry standards requiring large-scale heterogeneous instances to be solved in seconds. Given these challenges, we developed a multi-phase tailored randomized constructive heuristic. In a computational study involving real-life instances, our algorithm is benchmarked against dual bounds, the company's internal solutions, and commercial software, providing loading solutions of significantly higher quality in a few seconds while handling more practical constraints.

Besides improving efficiency of loading operations and increasing transport safety, the project allows potential annual savings estimated at around one million Euros and one thousand tons of CO_2. It also paved the way for further scientific research and contributed to establish an "analytics-based culture" at the company, that now plans to initiate new optimization projects and academic collaborations.

2 - Improving Global Risk Management of Emerging Health Threats with Facilitated Decision Analysis
Gilberto Montibeller, L. Alberto Franco

Emerging health threats, such as the Coronavirus global pandemic, create extensive health, economic and social problems. A key challenge for health experts and policy makers is deciding how to balance and reduce the risk of these threats. This research project on facilitated decision analysis for emerging health threats underpinned the development and implementation of innovative decision models and enhanced decision processes in two global organisations. The use of these operational research models and processes by health experts and policymakers achieved the following impacts: (i) enhanced the quality of health experts' recommendations to the UK Department for Environment, Food and Rural Affairs leadership in the prioritisation of animal and human emerging health threats; and, (ii) informed new international standards for the Food Standards joint programmes of the Food and Agriculture Organization of the United Nations and the World Health Organization.

3 - A Pilgrim Scheduling Approach to Increase Safety During the Hajj
Sven Müller, Knut Haase, Mathias Kasper, Matthes Koch

The Hajj — the great pilgrimage to Mecca, Saudi Arabia — is one of the five pillars of Islam. Up to four million pilgrims perform the Hajj rituals every year. This makes it one of the largest pedestrian problems in the world. Ramy al-Jamarat — the symbolic stoning of the devil — is known to be a particularly crowded ritual. Up until 2006, it was repeatedly overshadowed by severe crowd disasters. To avoid such disasters, Saudi authorities initiated a comprehensive crowd management program. A novel contribution to these efforts was the development of an optimized schedule for the pilgrims performing the stoning ritual. A pilgrim schedule prescribes specific routes and time slots for all registered pilgrim groups. Together, the assigned routes strictly enforce one-way flows toward and from the ritual site. In this paper, we introduce a model and a solution approach to the Pilgrim Scheduling Problem. Our multistage procedure first spatially smooths the utilization of infrastructure capacity to avoid dangerous pedestrian densities in the network. In the next optimization step, it minimizes overall dissatisfaction with the scheduled time slots. We solve the Pilgrim Scheduling Problem by a fix-and-optimize heuristic, and subsequently simulate the results to identify necessary modifications of the scheduling constraints. Our numerical study shows that the approach solves instances with more than 2.3 million variables in less than 10 minutes on average. At the same time, the gap between optimal solution and upper bound never exceeds 0.28%. The scheduling approach was an integral part of the Hajj planning process in 2007-2014 and 2016-2017. No crowd disaster occurred in these years. Our approach was not applied in 2015, when a severe crowd crush happened close to the ritual site. We briefly discuss possible causes and consequences of this accident.

■ MD-37

Monday, 14:30-16:00 - Virtual Room 37

GreenTech & GreenFin: Enabling Sustainable Investing leveraging Technological Innovation

Stream: AI & Innovation in Sustainable Finance
Invited session
Chair: *Alexander Posth*
Chair: *Peter Schwendner*
Chair: *Giacomo Morelli*

1 - Sustainable Patent Indicators for (Financial) Decision-Making: Overview, Domains, Groups, Empirical Support, and Sustainability Links
Carsten C. Guderian, Alexander Brem

Patents serve as valuable and frequently applied information sources concerning innovative activities. Focal to the corresponding literature is the conceptualization, examination, and application of novel patent indicators. By means of a literature review comprising 123 sources, we find that related research occurred in waves, progressing from the reliance on patent statistics of filings and grants towards patent citation counts and later indicators derived from the information contained within patents, for example inventors, assignees, or technology classes. Further, we classify patent indicators into 21 key patent indicator groups and 4 domains plus 3 domain combinations, each containing specific types of indicators and their derivatives. We link the concept of sustainability to patent analytics, patent indicator development, and patent valuation literature and discern sustainable from non-sustainable patent indicators. Herein, we provide indication of typical statistical results for these patent indicators and conject on future patent indicator development opportunities and their relevance for sustainable research and managerial decision-making. Our results are discussed in light of sustainable business models and typical sustainability use cases such as ESG investments. Particularly, we detect opportunities to relate financial and non-financial indicators for sustainable reporting and documentation. Moreover, the integrated use of patent indicators and financial metrics t

2 - Re-Evaluating the Empirical Determination of Cost of Capital for Green and Sin Stocks
Ahmed Badreldin, Bernhard Nietert

One of the most popular topics in ESG investing is the comparison of green and sin stocks regarding their cost of capital. To that end, empirical papers use the economic insights of theoretical models like Merton (1987) and Heinkel/Kraus/Zechner (2001) to justify differences between green and sin stocks and determine the size of these differences by means of regression. To make things worse, these regression-based cost of capital estimations are used as inputs to other empirical studies, for example studies that aim at attributing cost of capital to company characteristics or use cost of capital to explain mutual fund flows. Upon deeper analysis, it turns out that these empirical analyses are not accurately implementing Heinkel/Kraus/Zechner (2001)'s pricing formula since the formula of Heinkel/Kraus/Zechner (2001) results in factor loadings that are not regression coefficients. Put differently, the empirical papers are not implementing what they claim to be their theoretical basis. For that reason, we first, implement Heinkel/Kraus/Zechner (2001) in an empirically correct way. Second, we show that factor loadings from the correct model and regressions coefficients from the wrong implementation of Heinkel/Kraus/Zechner (2001) are significantly different, both statistically and economically. Third, we show that the same is true for cost of capital from the correct and the wrong implementation of Heinkel/Kraus/Zechner (2001).

3 - Design of flexible short-term energy contracts - An analysis of trading strategies on the continuous intraday market
Michael Naumann

Short-term fluctuations in electricity prices allow cost-optimized production scheduling by shifting energy-intensive processes to periods of favorable electricity prices, for which the day-ahead prices of EPEX Spot provide a reference point. However, the day-ahead prices represent the result of a finished auction and are therefore neither plannable nor tradable after the end of the auction. We propose the offering of short-term variable energy contracts for a brief period after the end of the day-ahead auction. Such contracts involve the flexible delivery of power on the following day at the market price of the day-ahead auction plus a premium for the offering energy trader. They would allow traders to pass on the day-ahead prices to the end customer and thus make them a predictable variable. The trader can buy the required amount of power at the continuous intraday market. We analyze the price differences on this market in relation to the contract price and thus the day-ahead price. We develop several trading strategies and test them empirically using the order books of EPEX Spot for different trading volumes. The strategies rely on the day-ahead price and the bid-ask spread. We show that, on average, a relatively small premium to the day-ahead price is sufficient for the trader to break even, with a slight increase in the premium for larger volumes. Finally, we identify renewable energy forecast errors in particular as drivers of the premiums.

4 - Stochastic Ordering of Systemic Commodity Risk
Giacomo Morelli

In this paper, we rank the contribution to systemic risk of the four major sectors of commodities, agricultural, energy, industrial metals, and precious metals, in light of a risk management perspective. We build four global minimum variance portfolios (GMVP), with daily rebalancing of the optimal weights, as representative of the four sectors of commodities. We fit four bivariate dynamic conditional correlation (DCC) GARCH models to estimate time varying relations between each GMVP of commodity and the VIX, the latter being recognized a well-known proxy of the state of the financial system. In particular, we evaluate the contribution to systemic risk of the four GMVPs computing the associated CoVaR, considering a phase of market stress when the returns of the GMVPs of commodities exceed the VaR. We backtest the results relying on classical backtesting procedures. Our findings show that the GMVP of Agriculture stochastically dominates Energy and Precious Metals for the entire period considered in the analysis, as suggested by smaller contribution to systemic risk.

■ MD-38

Monday, 14:30-16:00 - Virtual Room 38

Healthcare Logistics

Stream: ORAHS: OR in Health and Healthcare
Invited session
Chair: *David Barrera Ferro*
Chair: *Lisanne van Rijn*

1 - Design of a triage III patient classification model at the San Ignacio University Hospital
Laura Alejandra Cifuentes-Gaitan, Maria Jose Ruiz-Vasquez, Maria Angelica Chacon-Acosta, Sofia Sanchez-Prado, Ana Maria Beltran-Cortes, Eliana Maria Gonzalez-Neira

Triage is a system that classifies patients at emergency services to prioritize their attention. Patients classified in triage III are prone to have a worsening in the clinical profile. Nevertheless, the service required is not considered vital to classify them in categories I or II. Thence, a procedure for subcategorize patients of triage III into different care priorities was proposed, in such a way that the most serious cases of triage III could be attended with a higher priority inside its category. This research was carried out at San Ignacio University Hospital. We designed a classification algorithm based in CRISP-DM methodology. As predictors, we used demographic and vital signs variables. The missing data was imputed through the Random Forest method. For the modeling phase, we tested various classification methods such as KNN distance algorithm, Naive Bayes, multinomial logistic regression, individual trees, and random forest. We finally selected the balanced Random Forest with cross-validation due to its high predictive performance. The final model correctly classified 80.14%, 79.45%, 81.29% of the patients categorized as discharged, referred, and dead, respectively. Furthermore, the global accuracy was 80.15%. For the deployment phase, we highlight that the proposed model requires a constant updating of the training database and that the quality of the obtained results was affected given the low representation that the class "dead" had in the database.

2 - Planning Hospital Operations through Full Dimensional Efficient Facets
Marcos Estellita Lins, Maria Stella Castro Lobo, Henrique Rodrigues, Gabriel Soares

This work intends to support the resumption of a hospital productivity in the post-pandemic healthcare. The biggest challenge will be to make use of all the gains that the institution has obtained, in terms of installed capacity, due to the partnerships made, to increase its production and meet the existing repressed demand. For the management of the hospital work processes it is important to model and measure the performance in using its resources (human, equipment, beds) to produce services, namely the production function for the efficient frontier. We apply Data Envelopment Analysis (DEA) to support decision making in a big University Hospital in Rio de Janeiro. The method is appropriate for evidence-based decision making since it conjugates benchmarking best practices and weight attribution to inputs and outputs. DEA has been massively applied to support regulatory instances in comparing the performance of Decision-Making Units (DMUs). However, we apply DEA for supporting services production planning at the maximum possible level from the management perspective. Moreover, we demand that the efficiency measurement should take in account all the inputs and outputs before any expert judgement inclusion, and still make clear connections between primal envelope and dual multipliers model. For this, we restrict the frontier scope to the Full Dimensional Efficient Facets, if any, or to maximum efficient facets, using Mixed Integer Linear Programming.

3 - Use of social networks to forecast demand in a Health System
Leopoldo Lopez, Lorena Bearzotti, Raymundo Forradelas

The Health Network must be supplied to meet an unknown demand for pathologies in the population, this fact causes inventory break downs and poor human resource endowment. As the emergency department (ED) is a main entrance to hospitals, the unbalance material a human resource is reflected with long lines in this department, the lines are formed as patients cannot find a bed in the hospital so they must stay in the ED waiting, this is a concern that transcends any country. As patients waits in line in the ED, the medical team must decide who to take care next, therefore a triage is used to assess the severity of the patient illness, but Guzman (2017) showed that this assessment has por results. A better way to assess the patient gravity is using the medical history but develops countries don't have an Electronic Medical Records. This work explores the option of using social networks to improve the forecast of pathologies that will reach the Health System, understanding that the main entry to this system is through the Emergency Department.

4 - Site Reassignment For Mobile Outreach Teams: Investigating The Effectiveness Of Decentralized Decision-making
Lisanne van Rijn, Harwin de Vries, Luk Van Wassenhove

To improve access to healthcare, mobile outreach teams of healthcare workers visit remote sites to provide healthcare services. Dynamics in demand and supply cause once rational site-to-team assignment decisions to become suboptimal. This paper considers the problem to reassign sites to maximize effectiveness. Outreach teams commonly have much decision-making autonomy, but reassignment requires coordination. To study whether and when a decentralized approach is effective, we examine the trade-off between centralization and effectiveness and study how design choices and information gaps induced by centralization affect this trade-off. We use empirical data from six country outreach programs of NGO MSI Reproductive Choices. Our results suggest that simple decision-making systems, when properly designed, tend to perform close to centralized decision-making.

■ MD-39

Monday, 14:30-16:00 - Virtual Room 39

Warehouse and manufacturing logistics

Stream: Routing, Logistics, Location and Freight Transportation
Invited session
Chair: *Laura Vidal*

1 - Solving the capacitated family traveling salesperson problem.
Saúl Domínguez-Casasola, Jose Luis Gonzalez-Velarde, Yasmin Rios-Solis

Technology in some warehouses allows locations with different products, as well as products located in different locations. This has impacted the picking practices, since we need to decide which locations should be visited to fulfill orders. If the locations to pick are properly chosen, the distances traveled within the warehouse can be reduced, and thus have a favorable effect on the picking process. These new scenarios in warehouses, motivate the formulation of the capacitated family traveling salesperson (CFTSP), which is a variant of the generalized traveling salesman problem. Consider a complete and directed graph, where nodes are partitioned into disjoint families: The CFTSP consists in finding the subset of nodes that must be visited by the capacitated agents for each family to minimize the total distance traveled. This research incorporates not only a demand for each family on the graph but also a set of capacitated agents, and weights for each node families. To solve the CFTSP we propose a mixed integer linear programming model, a Biased Random-Key Genetic Algorithm and a matheuristic linking the genetic algorithm with the mathematical model.

2 - The impact of vehicle type selection on assembly line feeding
Ebenezer Olatunde Adenipekun, Veronique Limère, Nico André Schmid

In recent times, feeding mixed model assembly lines with parts has attracted the attention of practitioners and academic researchers. This can be attributed to mass customization which sharply increased the number of parts required at a single assembly line. The assembly line feeding problem (ALFP) is defined as the assignment of each part to a line feeding policy, with the goal of minimizing total material handling costs. While researchers have addressed the ALFP from different perspectives, limited efforts have been made towards the integration of the organization of logistics flows and individual part feeding decisions. Consequently, this study includes the integration of vehicle type selection and assembly line feeding decisions in an optimization-based model. We propose a mixed-integer programming model that, on the one hand, assigns each part to one of five distinct feeding policies and on the other hand, allocates vehicle types to carry out the associated material flows. The model includes route building and fleet size determination. The proposed model is solved for up to 60 artificial datasets. Each dataset contains variety of parts for 15 assembly stations. Detailed results will be discussed.

3 - A new model proposal for integrated order picking and vehicle routing problem
Esra Yasar Boz, Nil Aras

Today, companies want to access the products ordered as quickly as possible and at the lowest cost. In this case, two problems arise that supplier companies need to solve both inside and outside the warehouse. The first is the order picking problem related to the preparation of the order in accordance with the customer requests in the warehouse, while the other is the vehicle routing problem related to the delivery of the packed order to the customer. The problems are individually known as NP-hard and there are considerable publications in the literature for both. On the other hand, considering that a supplier company picks and sends dozens of orders from the warehouse every day, it seems a more realistic approach to take the problems simultaneously. Since there are few studies in the literature that deal with two problems in an integrated way, this problem called Order Picking Vehicle Routing Problem (OPVRP) can be seen as a relatively new problem. Until 2013, it is seen that routing and production processes were taken in an integrated manner, but order picking was ignored. In this study, a new integer linear programming model is proposed. The objective, constraints and decision variables of the model are defined, and then the model is run for small-sized samples using gams software. The outputs are promising that the model will be successful for large-scale real-life problems.

4 - A bi-objective model for the collaborative pickup and delivery problem under time windows
Laura Vidal, Sabine Limbourg

Urban logistics faces challenges such as congestion and pollution, prompting innovative collaborative projects to emerge. With the growth of e-commerce, customers want faster and flexible service. Government incentives should however, stress the need for a shift to greener delivery. In this sense, an intelligent platform for pooling and synchronizing urban logistics players' activities is under development in Wallonia. This research focuses on a Collaborative Pickup and Delivery Problem under Time Windows through a bi-objective of minimizing total transportation cost and environmental impact associated with each transport mode. The model is tested on a real case within Wallonia (Belgium). A profit distribution model should also be set to share the gains among the logistics operators who collaborated equitably. This project should make it possible to prioritize the use of electric vehicles such as cargo bicycles in city centres, but also to consolidate inter-urban deliveries in order to maximize the use of the vehicles on the road. Consolidation should thus maximize the loading of vehicles, hence reducing empty trips.

■ MD-40

Monday, 14:30-16:00 - Virtual Room 40

Multiobjective Branch & Bound/Cut/Prize Algorithms

Stream: Multiobjective Combinatorial Optimization
Invited session
Chair: *Britta Schulze*
Chair: *Michael Stiglmayr*

1 - Linear relaxation based multi-objective branch-and-bound

Nicolas Forget, Sune Lauth Gadegaard, Lars Relund Nielsen

Recent research has shown that decision space search methods are efficient for solving bi-objective problems with binary variables. Thus, there is a need to explore such techniques for the multi-objective case, i.e. for problems with binary variables and three objective functions or more. In this paper, we improve a branch-and-bound framework that can handle the multi-objective case. In particular, it uses the linear relaxation as lower bound set, and we propose a way to warmstart the computation of the linear relaxation at each node. The numerical experiments show that our procedure significantly reduces the computational time. Furthermore, we expose the challenges that arise when integer variables are introduced and adapt our framework to handle such problems.

2 - A hybrid scalarization method for multi-objective Branch and Bound algorithms

Julius Bauß, Michael Stiglmayr

While Branch and Bound (respectively Branch and Cut) algorithms are the gold standard for generic integer programming problems, objective space methods are dominating in multi-objective optimization. This objective space methods benefit from optimized single-objective solvers, while bounding is considerably weaker in multiple criteria. In this talk, we present a method to improve multi-objective bounding for bi-objective optimization problems. We use a dynamic branching strategy, which could be considered as "worst lower bound first". Weak lower bounds often prevent that nodes are fathomed by dominance, although they may not contain any new nondominated points. Adaptively, our method uses an IP-scalarization instead of the common LP-scalarization. This IP-scalarization is not applied to the subproblem, but to the root node, because all the points in the subproblem could be dominated. But the corresponding parameters are gained from the subproblem. The solution of this IP-scalarization gives us an improved lower bound face, which can be integrated in all remaining nodes of the algorithm. If we have not found this nondominated point so far, this also affects the upper bound. In this case, both the lower and the upper bound are updated, which also increases the probability of fathoming a node by dominance. We present preliminary numerical results showing that both the branching strategy and the IP-scalarizations have a significant impact on the number of created nodes.

3 - Sensitivity analysis in multiobjective mixed integer linear programming: The objective function coefficients

Britta Schulze, Kim Allan Andersen, Trine Krogh Boomsma

This talk is about a sensitivity analysis of the objective function coefficients in multiobjective mixed-integer linear programming. We define the sensitivity region in the sense that by changing one or several objective function coefficients the efficient set and its structure remain the same. In particular, we require that the ordering of non-dominated points is preserved and that dominated points remain dominated. We show how this ensures that the efficient set is the same upon the change in the coefficients. In detail we concentrate on changes to a single objective function coefficient. We first determine bounds on the sensitivity region by efficient solutions. We proceed to show that a subset of the dominated points can be excluded from consideration and determine the bounds on the sensitivity region by the remaining dominating points. In fact, we prove that it suffices to inspect the dominated points of a q-objective problem that are efficient in one of two related q+1-objective problems. Finally, we show that the sensitivity region is a convex set, i.e., an interval. Concluding, we show that the approach generalizes to simultaneous changes in two or more objective function coefficients and present a small computational analysis with the biobjective knapsack problem.

4 - Dual perspective of multiobjective integer programs using Tchebychev weight space decomposition and practical applications

Tyler Perini, Stephan Helfrich, Natashia Boland, Stefan Ruzika

Multiobjective discrete optimization (MODO) techniques, such as weight space decomposition, have received great attention in the last decade. The primary weight space decomposition technique in the literature is defined for the weighted sum scalarization, through which sets of weights are assigned to nondominated images. Recent work has added a new weight space decomposition defined for weighted Tchebychev scalarization, which provides the benefit of including all nondominated images but at the cost of "nice" convexity geometric properties. The current work applies the novel weight set decomposition as a "dual" perspective on existing MODO algorithms and includes strategies to improve algorithm design and measurement. First, we compare the added value of the new weight set decomposition by weighted Tchebychev by contrasting to weighted sum. Second, we present how existing "primal" algorithms return insufficient information to compute the weight set decomposition, then provide the necessary modifications and procedure. Lastly, we provide new approximation metrics (inner and outer) to be used for measuring algorithm performance in the weight space as well as an a priori approach to solving for a targetted subset of the nondominated set.

■ MD-41

Monday, 14:30-16:00 - Virtual Room 41

Future of public transport

Stream: Timetabling and public transport
Invited session
Chair: *Dennis Huisman*

1 - A semi-flexible feeder bus system for suburban areas

Fabio Vieira, Kenneth Sörensen, Pieter Vansteenwegen

This research investigates the operation of a semi-flexible demand-responsive feeder bus system. The feeder system is composed of a number of lines with a predefined initial route. These feeder lines bring all passengers from a low-demand area to a single transfer station and they are operated during a number of consecutive operation periods. The mathematical model optimizes the possible detours and shortcuts that buses on these lines are allowed to use, given the estimated demand for each bus stop during each operation period. The deviation policy includes detours of at most one or two bus stops and skipping some bus stops in the initial route. The objective function is to minimize the passengers' average travel time, including waiting time. Constraints limit the maximum travel distances of the buses. A simulation evaluates the system's performance for both the predefined initial routes and the semi-flexible demand-responsive routes. The model is used to optimize several instances, with an increasing number of empty bus stops. Results show that the more empty stops, the shorter the passengers' travel times using the semi-flexible service. Moreover, the detours of at most two stops obtain better results in passengers' average travel time than detours of at most one stop. However, a few passengers experience longer travel times due to the extended routes.

2 - Analysing Railway Network Capacity using Macroscopic Fundamental Diagram
Christopher Szymula, Nikola Besinovic

Railway professionals daily need to deal with the effects of limited capacity such as train path pricing or decisions on network design. For such tasks, the actual available capacity of infrastructure elements needs to be determined. Emerging from the infrastructure network and the operating regime, railway capacity is a wholistic systemic property. Consequently, the capacity of individual elements i.e. stations and corridors typically does not allow to adequately capture the corresponding network-wide effects. Thus, for capturing these network-effects, capacity needs to be assessed at a network level. This paper proposes a new generic model to assess railway infrastructure capacity of a given train line network, i.e. mix of trains with given heterogeneous frequencies. The presented model extends well known petri-nets and is capable of analysing a given line-network, operating at heterogeneous frequencies i.e. with differing numbers of trains. In addition, as an aggregated representation, the macroscopic fundamental diagram for the railway network (MFD-R) is derived. The MFD-R allows not only for assessing the networks capacity but also provides the expected level of service for different network loads i.e. number of trains per line. Thus, it can support railway professionals to efficiently assess, manage existing and propose extensions of networks and thus might contribute to the overall aim of providing sustainable transport by railway systems.

3 - Innovative public transport to stabilize and improve medical services in rural areas
Joachim R. Daduna

In many regions, medical care in rural areas is often inadequate and the service locations are difficult to reach for many of those affected. For years, this has led to a rural exodus and subsequently to undesired urbanization. Reasons for this is the insufficient mobility of some parts of the population, who for financial reasons do not have a car, or who are not yet able to get a driving license due to their age, or who are no longer able to drive a car due to old age or health problems. Developments in vehicle technology and advancing digitization are opening up new opportunities in the design of public transport services. The focus here is on autonomous vehicles that enable quasi-individual and demand-based service structures with a 24/7 service period. Key components here are free-floating car sharing systems and the use of mini- and midi-buses in the different forms of on-demand transport. However, it is not intended to replace existing public transport services, but they must be integrated into the existing structures in a suitable manner. For medical care, a hierarchically organized location structure makes sense in connection with functional decentralized concentration, especially from a cost perspective. However, it will be possible to extend this structure by retail trade and public services as well as leisure and entertainment. Hereby, the attractiveness of rural areas can be sustainably improved in the medium and long term.

4 - A large neighbourhood search algorithm to optimize a demand-responsive feeder service
Bryan David Galarza Montenegro, Kenneth Sörensen, Pieter Vansteenwegen

Feeder services are public transit services that transport people from a low demand, typically suburban, area to a high demand area, such as a transportation hub or a city. Here, passengers continue their journey using traditional forms of public transport. On the one hand, on-demand feeder services have been a topic of discussion in a number of recent studies, since these services can serve the demand efficiently. On the other hand, traditional feeder services with predetermined routes and timetables provide predictability and easier cost control. In this paper, a demand-responsive feeder service is considered, which combines positive characteristics of both traditional services as well as on-demand-only services. This feeder service has mandatory bus stops which are always serviced, as well as optional bus stops which are only serviced when there is demand for transportation nearby. To optimize the performance of this feeder service, a large neighbourhood search heuristic is developed. Experimental results on 14 benchmark instances illustrate that the LNS algorithm obtains solutions with an average gap of 1% or less compared to the optimal solution, within 1s of runtime. Larger instances can also be solved, typically in less than 60s. The results also show that the demand-responsive feeder service generally outperforms a traditional service in terms of service quality, often by more than 60%.

■ MD-42

Monday, 14:30-16:00 - Virtual Room 42

Developing sustainable supply chains

Stream: Sustainable Supply Chains
Invited session
Chair: *Cátia da Silva*

1 - eaSi-system - a framework for systematic SDG impacts assessment
Adrian Werner, Fabian Aponte, Moana Simas, Vibeke Nørstebø, Kirsten S. Wiebe

The UN's Sustainable Development Goals (SDGs) are increasingly integrated in business and public strategies. The goals' generic and partially contradictory nature, tensions between business strategies and societal development etc. pose, however, challenges. Decision makers need support to understand sustainability impacts of new technologies and to internalize SDG targets in their daily business. Interdisciplinary is central to today's research agendas, but new technologies and solutions are still assessed from the perspectives of research-area specific silos. Systems thinking should be used better to investigate consequences already at early decision stages. In our analysis we follow the natural steps of a new technology from invention to full deployment. We combine technology upscaling and market-uptake simulations with modelling of how up- and downstream global value chains are reshaped. Applying concepts of scenario development under uncertainty for allowing for different possible futures, we use the case of offshore wind technologies to show how short-term investment impacts and long-term structural change penetrate through the global value chain and affect the SDGs in different world regions. We identify synergies and trade-offs at the SDG indicator level and present both quantitative and qualitative impacts.

2 - Beyond adaptation: Changing supply chain management toward sustainability
Cynthia Waltho, Adel Guitouni

Supply chains are no longer straightforward chains, but often-complex networks with many actors involved in the production, processing, transportation, retailing, and waste management of products and services. The COVID-19 pandemic has further exposed the existing global interdependencies, as most businesses are reliant on international producers, suppliers, and customers. Nonetheless, as sustainability became a central concern, little attention has been paid to the question of the revisiting how sustainable supply chain management (SCM) should be theorised, taught, and managed. This paper contributes to the development of a theory to address the following major gaps: (i) supply chain networks are fragmented among multiple loosely dependent actors, (ii) the value created along supply chain is appreciated along different criteria (e.g., triple bottom line), and (iii) the value created by and the impacts of the supply chain operations accumulate and decay over time and across regions. We present examples of sustainable supply chain case studies to illustrate the proposed theory. We also discuss the implications for theory and practice of sustainable supply chain management.

3 - Green supply chain management practices: a comprehensive framework for its implementation
Mariana Trujillo Gallego, William Sarache

GSCM is an organizational approach that combines environmental issues and SCM, in order to reduce or minimize the adverse effects of products and operations on the environment. In relation to the study of the environmental practices of the GSCM approach, some authors affirm that their broad area of application impedes the establishment of a comprehensive framework. Therefore, although there have been numerous adoptions for GSCM practices, many researchers have stated the need to conduct further research on the relationships between multiple GSCM dimensions.

To address this gap, the present proposal aims to craft a new classification for environmental practices. Also, this study intends to propose a comprehensive framework based on Natural resource-based view and process view theory. The proposed framework classifies the GSCM practices into two types: First, the strategic practices which include eco-design, environmental collaboration, internal environmental management, green human resources management, and green information systems and technologies. Second, the operational practices that form the supply chain of a given product, from green purchasing and green manufacturing to green logistics and reverse logistics. The framework includes a classification of GSCM practices and vital measures to support effective GSCM implementation.

4 - Monetization Methods for the Design and Planning of Green Supply Chain
Cátia da Silva, Ana Paula Barbosa-Póvoa, Ana Carvalho

The growing environmental concern has led to the need of quantifying environmental impacts. In fact, there are many methods that allow the quantification of these impacts, but little information exists about how they can be applied, particularly at the supply chain level. In addition, most of these methods translate environmental impacts into abstract units poorly understood in the business context. Hence, this led to the need of quantifying environmental impacts in monetary units easily comprehended by decision-makers, since the economic and environmental performances of the supply chain can be compared in the same unit of measure. However, there is no information about how monetization methods can influence the design and planning of the supply chain and its performance. In this way, this work intends to overcome these gaps by studying different monetization methods to compare their performance at the supply chain level. By comparing the different monetization methods this work provides a significant contribution to identify the most adequate monetization methods in a supply chain context and to be able to apply them accurately. In addition, a MILP model is used to evaluate their suitability. A case study of an international company is studied.

■ MD-43

Monday, 14:30-16:00 - Virtual Room 43

Decision support in an epidemic context

Stream: Epidemiological modeling and decision support
Invited session
Chair: *Joana Matos Dias*

1 - How to Safely Reopen the Economy through Flexible Testing and Regional Coordination
Jiali Yu, Xinglu Liu, Lixin Miao, Zuo-Jun Shen

Our research focuses on public policy issues during the pandemic. First of all, we propose to increase testing capability by pooled testing, which tests multiple samples as one. We derive a simple mathematical tool that helps to adapt the testing pool size to minimize the number of tests per confirmed case. Moreover, we develop a spatial epidemic spread model to trade off the testing resource allocation and regional reopening level to restore most economic activities while containing the outbreak. We apply our approach to determine the reopening level of the five boroughs of New York City after the COVID-19 outbreak. We compare three reopening strategies, including i) the fairness heuristic, which has the same reopening level for all regions and allocates testing resources according to the population proportion; ii) the targeted reopening heuristic; iii) the targeted reopening and resource allocation heuristic. A targeted strategy can effectively increase economic activities while containing the outbreak. Our results contradict naive intuitions that we should reopen regions with the fewest infections and allocate more testing resources to regions with higher prevalence rates. To increase economic activities, we should first reopen regions with the most economic activities and allocate more resources to regions with more population mobility. Reopening the economy urges governments to step up regional cooperation to increase efficiency while avoiding new epidemic waves.

2 - Impact of school closures during an outbreak under unanticipated behavioural patterns of the public
Gozdem Dural-Selcuk

The humanity has been suffering from a global pandemic and it is not only health care services that has got affected, but also country wide community services, especially the education system. The first reaction as a non-pharmaceutical mitigation plan has been the closure of schools at all levels. There has been moderate amount of studies providing evidence that school closures during an influenza outbreak help total number of infections go down and result in a delay in peak times. However, the impact of human behaviour on the policy effectiveness is mostly overlooked. The rationale behind the policy of school closures is to decrease the contact rate among people and the mobility within/across the cities. Nevertheless, it is possible that people do not behave as they are supposed to do by modellers/decision makers. There is this possibility that school closures might increase the contact rate between the early-age and elderlies due to the needs of working parents for child care and/or it can increase the mobility of people across different geographical regions depending on the time of the year. As a result, the expected impact of school closures on the pandemic outbreak might be hedged against the side effects of unanticipated behavioural patterns of the public. In this study, we will construct a system dynamics model to explore the effectiveness of school closure policies in potential outbreaks under the impact of unanticipated behavioural patterns of the public.

3 - Confirmed forecasts for the expansion of the COVID-19 epidemic in the S. Paulo city, Brazil
Sergio Celaschi

An epidemiological compartmental model reported on May, 2020 was previously selected to estimate future outcomes to the dynamics of the Covid-19 epidemic breakout in the city of S. Paulo, Brazil. A time-dependent incidence weight on the reproductive basic number accounted for the Non Pharmaceutical Interventions (NPIs). A first series of official published data from March 1st to May 31st, 2020 was used to adjust the model parameters aiming to forecast one year of the COVID-19 evolutionary outbreak. The cohort study was set as a city population-based analysis. The population-based sample, 25,366 during the study period, was the number of confirmed cases on exposed individuals. The analysis was applied to predict the consequences of releasing the NPIs, and indicated the appearance of a second wave starting last quarter of 2020. By January 31st 2021, the number of confirmed cases was predicted to reach 0.49 Million (0.28-0.77), and fatalities would account for 22 thousand (11-32), 5 to 95% CRI. A second series of official data published from June 1st 2020 to January 31st, 2021 confirms all forecasts previously reported for the evolution of infected people and fatalities associated to this epidemic outbreak in the city of S. Paulo. By January 31st 2021, the official number of confirmed cases reached 469,657 (4 % above predicted average of accumulated cases), and fatalities accounted for 17,333 (19% above accumulated average of fatalities).

4 - Allocating and scheduling mobile vaccination teams to contain COVID-19 pandemic in Greece
Ioannis Tsagarliotis, Nikolaos Rachaniotis

COVID-19 pandemic has a major impact not only on world economy but also on daily life standards. Several vaccines have been developed or are under development in order to contain the pandemic and as of January 2021 three of them have been authorized/validated by international regulatory authorities. Vaccination in Greece initiated at the end of December 2020 and it is taking place in vaccination centers (health centers, hospitals, etc.) that are distributed nationwide so that no part of the country is left uncovered. For the cases of individuals living in institutions such as nursing homes, care facilities for chronically ill, rehabilitation centers, for house-bound individuals and reception centers for refugees, specialized mobile vaccination teams are assigned. This paper focuses on the problem of allocating and scheduling these mobile vaccination teams, having as an objective to minimize the number of new cases.

■ MD-44

Monday, 14:30-16:00 - Virtual Room 44

Julia: New Kid on the Block

Stream: Practice of OR (Making an Impact)
Invited session
Chair: *Joaquim Gromicho*

1 - Julia: New Kid on the BlocK
Joaquim Gromicho

How can you make best use of Julia? Do you want to try? This tutorial will explore how Julia compares with Python, and introduce you to its use in the OR/analytics context.

For the latest details on this or any of the other sessions in 'Making an Impact', please visit the 'Making an Impact' webpage https://euro2021athens.com/specific-sessions/

■ MD-45

Monday, 14:30-16:00 - Virtual Room 45

Production planning

Stream: Production, Service and Supply Chain Management
Invited session
Chair: *Mirjam Meijer*

1 - A multi-objective mixed-integer linear programming model for the dynamic cell formation problem
Laura Escobar, Edwin Garavito, Leonardo H. Talero-Sarmiento

The Dynamic Cellular Manufacturing System (DCMS) is one of the best production systems in order to increase flexibility, agility, and efficiency in the use of production equipment. As an illustrative example, this work examines a multi-period planning horizon in a dynamic environment with the demand and product-mix changing in each period, resulting in cell reconfiguration necessity.

We developed a multi-objective mixed-integer linear programming model for the dynamic cell formation problem (DCFP) based on the literature. This model simultaneously integrated three objective functions the cost-minimizing associated with the purchasing, disposal, relocation, fixed costs of each machine, and material handling across cells and periods while minimizing the workload balance variation and maximizing the machinery availability of the production system. Finally, the model validations consist of some numerical examples using computing software GAMS 23.5.1.

2 - Taming the Bell Curve in LED production
Anand Paul

This paper studies the challenges involved in LED production planning, where the production output is characterized by a stochastic distribution over the targeted production metric; thus the whole range of production is not suitable for a specific application. Our goal is to determine the optimal policy for process settings, so as to better control the yield distribution and meet contractual commitments. We formulate a stochastic profit optimization problem for a given set of orders, and determine the optimal production parameter setting and batch sizes to meet a target service level. The results suggest that the optimal policy may change based on the characteristics of the underlying production distribution and tolerance level. We show that even under symmetric cases, the intuitively appealing "mid-point policy" is not necessarily optimal. Our analysis highlights how the percentage yield and batch size are impacted by service level agreement.

3 - Synchronization in a Two-supplier Assembly System: Combining a Fixed Lead-time Module with Capacitated Make-to-Order Production
Mirjam Meijer, Willem van Jaarsveld, Ton de Kok

A high-tech manufacturer often produces products that consist of many modules. These modules are either sourced from one of its suppliers or produced in-house. In this paper, we study an assembly system requiring two modules. One module is sourced from a supplier with a fixed lead-time, while the other module is produced by the manufacturer itself in a make-to-order production system. Since unavailability of one of the modules causes costly delays in production of the end-product, it is important to align in-house production with the ordering policy of the lead-time module. We consider two models: a continuous time model and a discrete time model. In the continuous time model, we assume Poisson distributed demand and a single-server production system with exponential production times. We propose an order policy for the lead-time module with base-stock levels depending on the number of outstanding orders in the production system of the in-house produced module. We prove monotonicity properties of this policy and show optimality. Numerical experiments demonstrate that the proposed policy can generate considerable savings compared to a base-stock policy with fixed base-stock levels. In the discrete time model, we assume a certain capacity per period than can be either fixed or random. We show that a base-stock policy with state-dependent base-stock levels is again optimal.

■ MD-46

Monday, 14:30-16:00 - Virtual Room 46

Analysis of Stochastic Production and Retail Systems

Stream: Stochastic Models in Manufacturing and Services
Invited session
Chair: *Stella Kapodistria*

1 - Bayesian Process Control for Critical Systems
Collin Drent, Stella Kapodistria

We consider the joint optimization of preventive maintenance and process control of manufacturing equipment used for production processes. Thereto we assume that there is a process characteristic such that i) the production quality depends on this characteristic, and ii) the equipment fails if this characteristic deviates too much from the perfect operational state. The evolution of the process characteristic is modelled as a Brownian motion with unknown drift that is inferred in a Bayesian way from observations at equidistant epochs. At each epoch, either preventive maintenance is performed or the production process is continued - with the risk of failure of the manufacturing equipment. To model the decreased product quality, we assume that operational costs are increasing in the absolute deviation of the process characteristic from the perfect operational state. We first show that the current position of the process characteristic and age of the production process are sufficient statistics for the inference of the unknown drift, which allows us to subsequently formulate the problem as a Markov decision process encoded on these two variables. We then characterize the structure of the optimal policy under both the average and discounted cost criterion, and show that it has an intuitive bandwidth structure with monotonic control limits. Numerical results show that the Bayesian policy performs excellent compared to a clairvoyant policy that knows the true drift.

2 - Solving the buffer allocation problem in tandem lines with machine learning techniques
Joost Berkhout, Nanne Dieleman

The Buffer Allocation Problem (BAP) is an NP-hard combinatorial optimization problem that is often solved to design queuing networks. One of the problems of BAP is that the throughput of a queuing network cannot be determined analytically in most cases. Therefore, a BAP solution method consists of an evaluative method and a generative method. The evaluative method is used to evaluate the throughput of the system, and the generative method is used to find a (near) optimal buffer allocation. Monte Carlo simulations are often used as evaluative methods, but these have extensive running times. Other evaluative methods, such as decomposition approaches, are often limited to specific queuing networks.

Machine learning techniques such as neural networks provide new opportunities to create evaluative methods. In this work, a neural network metamodeller is developed that accurately and efficiently approximates the throughput of many different tandem lines (with varying rates, number of stations, etc.), thereby extending the state-of-the-art BAP solution methods. Moreover, adding theoretical queuing knowledge to the training data further enhances the performance of the metamodeller. By using an evolutionary algorithm as a generative method, it is shown that the metamodeller reaches good solutions in a fraction of the time that is required by a simulation-based evolutionary algorithm.

3 - An extended newsvendor problem formulation for setting up flexible capacity
Fereidoun Rashidi, Ralf Gössinger

We consider a risk averse manufacturer who wants to set up capacity for a production system that is faced with stochastic capacity requirements of different types. In order to cope with random fluctuations, total capacity is generated in a flexible way by multiple, non-consumable, indivisible resources. Thereby, volume and product flexibility build on the options of activating/deactivating resources as well as determining their degree of utilization. As soon as the resources differ in terms of cost, capacity level and abilities, a combinatorial problem arises. The involved decisions form a hierarchy: For setting up capacity, the basic decision on the resource configuration has to be made. Building on that, adaptation decisions on activation and utilization of individual resources contained in the chosen configuration are to be taken subject to possible requirements scenarios. For this capacity planning situation, we formulate a stochastic (scenario-based) MILP model that takes the risk attitude of the manufacturer into consideration. In addition, we inquire the structure of optimal solutions to this problem by means of a full-factorial numerical study and related statistical analyzes.

■ MD-47

Monday, 14:30-16:00 - Virtual Room 47

Emerging Collaborative Economics and Management under Uncertainty 1

Stream: Emerging Collaborative Economics and Management under Uncertainty
Invited session
Chair: *Sırma Zeynep Alparslan Gök*
Chair: *Gerhard-Wilhelm Weber*

1 - Mitigate COVID spreading in industrial and business areas using Carpooling service
Josep Maria Salanova Grau, Zisis Maleas, Georgia Ayfantopoulou, Maria Konstantinidou, Panagiotis Tzenos, Thanasis Tolikas

The COVID outbreak enforced many sectors including work offices to reconsider most of their daily habits. Working places are one of the most usual ways to spread the virus. Additionally, even if public transport doesn't considered as an outbreak source, this state changing when the busses operate overcrowded. The main goal of this study is to provide shared mobility services to commuters using carpooling matching service. Especially, this work deal with many-to-one and one-to-many carpool problem. Indeed, it presents a combinatorial optimization program with primal heuristic steps to solve the carpool problem in an optimal and time-efficient way with respect to commuters' schedule constraints and COVID social distancing constraints. Finally, some performance analytics presented along with concerns on how OR tools reflect the people's needs. Lastly, there is a discussion on which sciences may also contribute to such services and take into account behavioral or economic aspects of the problem.

2 - High-fidelity Benchmarks for Urban Delivery Problems
Gabriela Surita, Fillipe Goulart, Juan Fonseca-Galindo, Andre Lemos

The Vehicle Routing Problem and its variants have received significant attention in the field of transportation and logistics. Despite the continuous progress in developing techniques and algorithms, the datasets employed in many works still lack resemblance to the real world, particularly compared to last-mile same-day cases. More specifically, most benchmarks are fairly small, seldom reaching thousands of customers when tens of thousands are commonplace in urban areas; the deliveries follow artificial probability distributions instead of real historical data; and the distance measure tends to be Euclidean, hence neglecting the geographical conditions of the cities.

This work attempts to overcome these issues by proposing a large-scale dataset with deliveries from 3 large metropolitan areas in Brazil collected over 120 working days, dubbed LoggiBUD. We synthesize the instances from public sources that correlate well with actual deliveries performed by Loggi. We propose evaluating results in street distances provided by OpenStreetMaps, thus granting them with a nice industry-standard similarity. With this dataset, we present three challenges with increasing difficulty levels. We believe the more realistic character of our work will be useful in supporting further studies and collaborations between researchers and practitioners from academia and industry on urban delivery problems.

3 - Joint Optimization of Energy Storage Sizing and Transmission Line Capacities for an Island System
Arya Sevgen, Abdullah Dasci

In this work, we present a stochastic mixed-integer programming model to optimize the sizes of two different kinds of energy storage systems and the capacity of the transmission lines for an island system. We consider an island where the main generation source is wind and alternative source is diesel. The primary aim of this study is to investigate the investment decisions in storage and to determine energy capacities and power rates of the storage systems while minimizing the construction, O&M, and diesel costs. By deploying two different storage types at different places, we investigate the circumstances where installation decisions change. Stochastic renewable energy generation and demand are taken into account by considering different scenarios which are reproduced based on real data. First-order Markov chain is used to generate monthly wind power time series. Numerical experiments are conducted to investigate the effect of the cost parameters on the system design.

We present a stochastic mixed-integer programming model to optimize the sizes of two different kinds of energy storage systems and the capacity of the transmission lines while minimizing the total cost for an island system. Stochastic renewable energy generation and demand are taken into account. Numerical experiments are conducted.

4 - Serious Business Games in Port's Container Yard Management
Jannis Walz, Leif Meier

Yard Management is probably the most interesting and - at the same time - most demanding planning problem for container terminals in logistics:

Yard Planners need to decide which container where and when to be stacked in the yard, considering connected processes and given business targets.

The University of Applied Sciences in Bremerhaven is deeply connected with container logistics management: Bremerhaven, Germany, is locating Europe's Top 5 container port with an annually handled volume of approx. 5 million TEU.

We designed "The Yard is The Heart", a serious business game that is applied in Bremerhaven's logistics education.

In this Business Game, users are able to design yard strategies and simulate results of their strategies for complex yard management decisions.

The strategy design is based on a realistic interface model, the business game can therefore also be applied in real terminal case.

We consider multiple business targets and analyze the success of each yard strategy against conflicting KPI.

Results from simulation runs are shown in 3D-animations and deliver a summary report and access to raw simulation data for results analysis.

In our evaluations we tested medium-size terminals and managed 20.000 container movements within one simulation.

■ MD-48

Monday, 14:30-16:00 - Virtual Room 48

Bissan Ghaddar

Stream: Keynotes
Keynote session
Chair: *Gabriele Eichfelder*

1 - Polynomial Optimization in Power and Water Network Operations
Bissan Ghaddar

Several challenging optimization problems in power and water networks involve both operational decisions and non-linear models of the underlying physics described by the network. However, these networks exhibit a nice sparse structure. This talk provides an overview of approaches that combine recent advances in conic relaxations of polynomial optimization problems along with exploiting structure of the underlying problem. These approaches are demonstrated on applications arising in power and water networks.

■ MD-49

Monday, 14:30-16:00 - Virtual Room 49

AI4RAILS II

Stream: The 2nd International Workshop on Artificial Intelligence for RAILwayS (AI4RAILS)
Invited session
Chair: *Rob Goverde*

1 - A Multi-Agent Approach to the Train Unit Shunting Problem
Wan-Jui Lee, Quintess Barnhoorn

The scheduling of tasks and planning of movements in shunting yards is quite complex and is known as the Train Unit Shunting Problem (TUSP). To overcome the limits of Single-Agent Deep Reinforcement Learning (DRL) approaches, a Multi-Agent DRL approach for TUSP is developed in this work. TUSP was modelled as a Markov Decision Problem in which the agents control train units. That is, each train unit has an agent that decides its actions. The agents have the options to move, setback, split, combine, service or wait, and each train unit acts individually. The weight sharing framework is adopted to reduce the number of parameters in deep neural networks that need to be stored and make the number of parameters independent of the number of agents. Cooperation mechanisms among agents have also been developed. By modelling the TUSP with individually acting train units, our Multi-Agent DRL approach has shown to be able to learn strategies to solve the TUSP and generate more consistent plans. This makes it a viable approach to research further. Its performance is, however, still subpar compared to the local search approach. Local search is a heuristic method for solving computationally hard optimization problems and requires an initial plan as input. The quality of the resulting plan is dependent on the quality of the initial plan. Therefore, our Multi-Agent DRL approach could be used to deliver more consistent and explainable initial solutions to the local search as an auxiliary.

2 - TORS: A Train Unit Shunting and Servicing Simulator
Jacobus G.M. van der Linden, Jesse Mulderij, Bob Huisman, Joris den Ouden, Marjan van den Akker, Han Hoogeveen, Mathijs de Weerdt

When trains are finished with their transportation tasks during the day, they are moved to a shunting yard for maintenance. Public transportation by rail is expected to remain growing for the next decades. However, most maintenance hubs are located in dense urban areas where space is very limited, while the pressure to reduce costs increases. The challenge is to enable more transportation volume without extending the rail infrastructure significantly and to offer robust services to passengers. Scheduling the routing, parking, cleaning and maintenance checks of trains is known as the Train Unit Shunting and Servicing (TUSS) problem. It integrates several known individually hard problems while incorporating many real-life details. We present an event-based simulator called TORS (Dutch acronym for Train Shunting and Servicing Simulator) that encapsulates the most important practical details of the TUSS problem. In TORS, users can choose actions such as routing a train from one track to another or cleaning it. TORS then validates the action and updates the state according to the input. Our contribution is twofold: First, we provide a translation of a real-world problem to a conceptual model to accommodate researchers from AI and Operations Research to test their methods in this practical context. Second, with this simulator we facilitate a comparison of different methods and development of new algorithms to solve the train unit shunting and servicing problem.

3 - An Evolutionary Approach to Solve the Train Unit Shunting and Servicing Problem
Casper Athmer, Mathijs de Weerdt, Laurens Bliek

The Train Unit Shunting and Servicing Problem (TUSP) is a NP-hard problem encountered by railway operators, which involves parking, servicing and routing trains on a shunting yard, and matching incoming trains to outgoing trains. Currently, no exact algorithm exists that can find feasible solutions for this problem for real-world instances. Instead, heuristics are used. The Dutch Railway operator (NS) currently uses an Iterated Local Search method (named HIP) to solve TUSP. The goal of this research is to improve HIP by combining it with an Evolutionary Algorithm (EA). Generally, local search is good at exploitation, but has more trouble with exploration, and can therefore get stuck in a local optimum. HIP does account for this by adding random walks (i.e. exploration), however, this is unguided and there is no way of telling if the exploration goes in the right direction. In this research, an EA is designed that uses domain knowledge during parent selection and crossover to guide the search. Since local search is superior in exploitation, the EA is combined with HIP, to get the best of both worlds.

Experiments show that, of 50 problem instances on an artificial shunting yard, HIP managed to solve 39, while the EA solved 43 (given the same number of maximum function evaluations). More experiments on locations from the real world are needed to determine whether the EA can consistently outperform HIP.

4 - Contextual hyperparameter optimization for the Train Unit Shunting Problem
Leon van der Knaap, Laurens Bliek, Mathijs de Weerdt

One of the planning problems that is encountered by the Dutch Railways (NS) at shunting yards is the Train Unit Shunting Problem (TUSP). This problem considers idle train units that have to be parked, be cleaned, undergo regular maintenance, and be reconfigured into the scheduled departing train compositions. A local search procedure is being developed to solve this problem at all shunting yards in the Netherlands.

This research considers the optimization of the hyperparameters of this local search algorithm. We take contextual information into account to construct a mapping of instance-specific problem features to different hyperparameter configurations. General difficulties when regarding hyperparameter optimization are the expensive function evaluations of the target algorithm, that place a tight budget on the number of possible configurations to query; and noisy observations of this function. Therefore, we resort to using Bayesian optimization to construct a surrogate that models our belief of the unobservable function. Additional encountered difficulties for this specific problem are heterogeneous problem instances and the underlying problem to be a constraint satisfaction problem (instead of the more commonly studied optimization problem). We show that these difficulties prevent an instance-specific approach and result in a poor generalization from the performance on the training set to test data.

■ MD-50
Monday, 14:30-16:00 - Virtual Room 50

Jaap Spronk's legacy

Stream: Memorial Session - in honour of Jaap Spronk
Invited session
Chair: *Karen Watkins*
Chair: *Lorenzo Peccati*

1 - Jaap Spronk and his view of Finance
Edgaro Ortiz

Jaap had created the EWGFM in 1987 and was constantly ahead of us...

2 - Jaap Spronk and his Italian Legacy
Giorgio Consigli, Benedetto Matarazzo, Onno Steenbeek, Lorenzo Peccati, Giovanni Zambruno

Jaap has always been an innovator and one of his main goal was to deal with many issues that should have been addressed in finance. For Jaap Finance had become a philosophy that influenced both the way of thinking and the behavior of managers and organisations. Many of these issues are becoming to be faced by financial academia .

3 - Jaap and the EWGs
Pekka Korhonen, Thomas Hartman, Anoop Rai, Ephraim Clark, Alain Chevalier, Karen Watkins, Yvonne Spronk

Jaap founded in 1986 the Euro Working Group for Financial Modelling. He was a very active member of the EWG for Multi Decision aids. He ran the EWGFM until 2009 when he left the chair to Rita D'Ecclesia. He created the Global Executive Master for Financial Management an international association. . . .

4 - The special contribution of Jaap Spronk
Lorenzo Peccati

Our dear friend Jaap Spronk left us an important heritage ....

■ MD-51
Monday, 14:30-16:00 - Virtual Room 51

OR in Military, Defense, and International Security

Stream: OR in Military, Defense, and International Security
Invited session
Chair: *Eray Cakici*

1 - Feasibility analysis of Drones for National Defense based on a Multimethodology
Ygor Logullo, Miguel Moreira, Mischel Carmen N. Belderrain, Amanda Silva, Carlos Francisco Simoes Gomes, Marcos dos Santos

There is a hypothetical necessity of Brazilian National Defense as for the implementation of RPAS (Remotely Piloted Aircraft Systems), commonly known as drones, in their tactical and strategic operations. Even the RPAS providing countless applications and even replacing the use of conventional aircraft, piloted by onboard pilots, a lack of better exploitation of the problematic situation was identified, starting from the following questioning: Why is it necessary to use RPAS in National Defense operations and what is the purpose of a particular implementation? Furthermore, if Brazilian security sectors and military forces would like to implement those systems, which would be the best choices? Develop or buy technology? Use in which areas and missions? In this context, we propose to use a Multimethodology for structuring the problematic situation based on Value-Focused Thinking (VFT), combined with Multiple Criteria Decision Analysis (MCDA) approaches. The multimethodology proposed, in addition to providing a better understanding of the problem, identifying the strategic and fundamental objectives, makes it possible to solve a decision problem using a Multiattribute Value Function, providing an indication of an enlightened solution. Therefore, the contribution of this paper is providing an objective-driven approach and a holistic understanding for supporting that strategic decision in Brazilian National Defense.

2 - Artillery Firing Shift with Two Registration Targets
Michael Bendersky, David Raz

Firing Shift is the shifting of artillery fire from one target ("registration") to another with the application of corrections determined from the adjustment on the first target to the initial firing data on the second ("application"). In this paper we introduce a shift method based on simultaneous firing at two different registration targets rather than a single one. We show how to use the observed data to solve explicitly for four major environmental parameters which affect ballistic trajectories and update them consequently for the application mission. We determine the distribution of the remaining error at the application and compare the resultant accuracy with that of the existing correcting algorithm. Numerical examples are included. They show the big potential of the proposed method.

3 - A Semi-Markov Decision Model for a patrol problem with stochastic attack times
Constantinos Karamatsoukis

We consider a patrol problem in a line graph, in which attackers are trying to invade into one of its nodes, according to a probability distribution. Those kinds of attackers are called random attackers. It is assumed that the time each attack lasts is a continuous random variable and it is assumed that the travel times between consecutive nodes are constant but not equal. The patroller travel across the line graph to detect potential attacks at nodes. We propose a Semi-Markov Decision Model to find the policy that minimizes the total expected cost incurred. A suitable algorithm is developed in order to find the optimal patrolling policy. Numerical results are also presented for the problem we study.

4 - Navy Training Scheduling
Eray Cakici, Qiannan Gao, Hanadi Wali, Gianmaria Leo

This study is motivated by optimizing the training schedules of military recruits and civilian professionals involved in naval operations. The scheduling problem is type of a resource-constrained problem as recruits are required to take certain courses and each course requires a set of resources. Courses are associated with a capacity, a duration and can be constrained by precedence relationships, i.e., a recruit can only start a certain course after completing the pre-requisite. Each recruit has a designated mission and needs to complete all required courses in order to be assigned to their mission. And each mission is associated with a date (due date). Therefore, main objective is to maximize the number of recruits completing required courses before their mission's due date. Problem can also be viewed as a job-shop scheduling problem with batching machines. Each job needs to go through certain operations and each operation can be performed by a batching machine with the objective of minimizing number of tardy jobs. Different objectives such as average and maximum delay on satisfying the mission due date are also introduced to the problem in order to generate more robust schedules. Efficient constraint programming (CP) and mixed-integer programming (MIP) models are presented to address this challenging and multi-objective problem. Computational analysis show that the proposed CP model significantly reduces computational time compared to the MIP model.

■ MD-53

Monday, 14:30-16:00 - Virtual Room 53

Specific Applications of Stochastic Modeling and Simulation in Engineering, Management and Science 2

Stream: Specific Applications of Stochastic Modeling and Simulation in Engineering, Management and Science
Invited session
Chair: *Rob Zuidwijk*

1 - Generator and Line Maintenance Planning with Operations Scheduling under Sensor-Driven Unexpected Failures
Bahar Okumusoglu, Beste Basciftci, Burak Kocuk

In this study, we focus on a short-term integrated generator and line maintenance planning with operations scheduling problem while considering the unexpected failure possibilities of these system elements. We formulate this problem as a two-stage stochastic mixed-integer program with failure scenarios sampled from the sensor-driven remaining lifetime distributions of the individual elements. The first stage of this stochastic program focuses on the maintenance scheduling problem, whereas each second stage subproblem corresponds to a unit commitment problem under a failure scenario. To solve the resulting large scale stochastic program, we propose a solution approach that combines the features of the integer L-shaped method with scenario decomposition algorithms. Furthermore, we exploit the special structure of the maintenance and operations scheduling problem to derive stronger optimality cuts that are integrated into the solution procedure implemented in parallel fashion. To illustrate the success of our condition based modeling paradigm compared to more conventional maintenance approaches, we design a computational study focusing on a weekly plan with daily maintenance and hourly operational decisions involving detailed unit commitment subproblems. Our preliminary computational results on various instances demonstrate the computational efficiency of the proposed approach with reliable and cost effective maintenance schedules.

2 - Digital platforms and maximum matching in random bipartite graphs
Rob Zuidwijk

Truck haulers may use a digital platform to match their import and export orders to create truck routes with less empty kilometers. Sharing orders through such a platform is beneficial as it will allow for better matches taken from a bigger pool of orders. Quantification of this network effect inspired the study of the expected size of maximum matching in random bipartite graphs. Both the motivating example and upper and lower bounds for the expected size of maximum matching are explained.

3 - Information Retrieval under Network Uncertainty: Robust Internet Ranking
Anna Timonina-Farkas, Ralf Seifert

Internet ranking algorithms play a crucial role in information technologies and numerical analysis due to their efficiency in high dimensions and wide range of possible applications, including scientometrics and systemic risk in finance (SinkRank, DebtRank etc.). The traditional approach to Internet ranking goes back to the famous work of Sergey Brin and Larry Page, who developed the initial method PageRank (PR) in order to rank websites in search engine results. Recent works studied robust reformulations of the PageRank model for the case when links in the network structure may vary, i.e., some links may appear or disappear influencing the transportation matrix defined by the network structure. We make a further step forward, allowing the network to vary not only in links, but also in the number of nodes. We focus on growing network structures and propose a new robust formulation of the PageRank problem for uncertain networks with fixed growth rate. Defining the robust PageRank in terms of a non-convex optimization problem, we bound our formulation from above by a convex but non-smooth optimization problem. Driven by the approximation quality, we analyze the resulting optimality gap theoretically and demonstrate cases for its reduction. Furthermore, we propose a coordinate-wise descent method with near-optimal step size and address high-dimensional cases using multinomial transition probabilities.

4 - Goal programming model for managerial decision making in a family business - case study in a textile business
Sivaramakrishna Prasad, Prabhakar R, John Raj, Arul E

In small and medium enterprises, especially in family businesses, there are many challenges and it is difficult to get assistance. An expert system is proposed taking into account management inputs. The system proposed, takes into account the characteristics of family business decision making to determine goals for the business under existing/perceived estimated environment. A goal programming model has been proposed in the textile business at hand, based on the results of the expert system and market estimates, which is used to find the achievements of goals. A software package was developed using C++ for the expert system and goal programming which is used to get results. The results are used for execution, as well as fine tuning the expert system and management inputs. This method is very useful for family based small and medium enterprises.

■ MD-63

Monday, 14:30-16:00 - Virtual Room 63

Last minute changes 1

Stream: Last minute changes
Invited session
Chair: *Milad Elyasi*

1 - Prioritizing patients for cancer prevention programs
Maria-Carolina Poveda-Amaya, David Barrera Ferro, Sally Brailsford, Diego Patino, Raul Murillo

In Colombia, cancer is still considered a public health problem due its incidence and mortality rates. According to GLOBOCAN 2018, nearly 126 men and women die daily in the country from this disease. Therefore, early diagnosis and timely access to treatment are essential. However, screening and prevention programs continue to face major implementation challenges. This work proposes the use of machine learning techniques to predict the probability of developing cancer, using administrative health data. We aim at generating new information to support the prioritization of asymptomatic patients in preventive care programs. First, care pathways are modelled for a group of patients using a one-year period of electronic health records. Then, sociodemographic information, historical records of prescribed medications, diagnoses and procedures are used to train different classification algorithms. Models performance is assessed using the average AUC score from a 10 by 10 cross validation process. Preliminary results show accuracy of the models and will be use to design a Decision Support System.

2 - Applying Machine Learning to improve Operation Room Scheduling under uncertainty
Ricardo Otero

Operating room management in surgical services is an attractive area for managers and researchers due to its influence on hospitals' financial performance and quality of care. In a real-world setting, planning and scheduling depend on usually unknown inputs such as surgery duration. Simulation-Optimization approaches have been used to deal with this uncertainty. Nevertheless, adapting probability distributions or building a finite set of scenarios for unknown parameters is a complex task due to the possible dependency on other variables and the potential lack of available data. Moreover, it has been shown that high variability in stochastic parameters in combinatorial optimization problems has a significant effect on the expected performance of a solution. In this paper, we propose using Machine Learning algorithms to predict surgery duration and use the prediction errors inside an Optimization-Simulation approach using bootstrapping. Then, combining the simulation with a genetic algorithm, we seek to obtain robust schedules. With real-life data from a Hospital in Colombia, our method achieved better room utilization than the probability distribution approach and the hospitals' schedule.

3 - Blood Donation Tailoring under Demand Uncertainty
Milad Elyasi, Okan Ozener, Ihsan Yanikoglu, Ali Ekici

Donation tailoring becomes a challenging optimization problem to be solved in practice when the technical complications, e.g., deferral times, perishability of blood products, limited donor pool and uncertainty, of storing and harvesting the blood products are added to the increasing demand for blood products. Even though multi-component apheresis yields better deferral time and inventory management of blood products compared with the whole blood donation because it harvests only the required product(s) from each donor, the tailoring management that adopts multi-component apheresis with nominal data is often far from being perfect because of demand uncertainty and limitations of the donor pool. This study proposes a mathematical optimization method for a donation tailoring problem that uses multi-component apheresis under demand uncertainty. The uncertainty is modeled using scenario sets, and the donor pool is divided into two groups as here-and-now and wait-and-see: here-and-now donors are scheduled for donation at the beginning of the planning horizon, and their schedules are fixed regardless of the scenario realized; while the wait-and-see donors are flexible and their schedules are adjustable according to the realized portion of demand in the rolling horizon. We propose a column generation approach to solve the associated multi-stage stochastic donation tailoring problem. The effectiveness of the proposed approaches is shown through extensive numerical analyses.

4 - An Adjustable Robust Optimization Approach for Emergency Relief Routing Problem
Farzad Avishan, Milad Elyasi, Ali Ekici, Okan Ozener, Ihsan Yanikoglu

The response phase of a disaster covers the first 12 hours after the occurrence, and it is prone to travel time uncertainties because of debris and gridlock traffic. Rescue teams have limited resources and time, and they must prioritize the critical needs of affected people and distribute supplies as much as possible within the given time limit. This paper proposes an adjustable robust reformulation framework for the associated humanitarian logistics problem that creates routes for rescue teams and decides the service times of the visited sites to distribute relief supplies by taking the uncertainty in travel times into account. The associated model allows rescue teams to adjust their service decisions according to revealed information during the process, i.e., our solutions are robust for the worst-case uncertainty travel times but still more flexible and less conservative than the static robust optimization. We propose novel reformulation techniques to model adjustable decisions. The resulting models are computationally challenging optimization problems to be solved by exact methods, and this is why we propose a two-phase heuristic algorithm that yields near-optimal results for medium-sized instances and yields efficient solutions for real-sized instances that cannot be solved by commercial solvers. We apply proposed models to a data set that comes from a disaster case in Turkey to show and evaluate the effectiveness of the proposed solution algorithms.

Monday, 16:30-17:30

■ ME-21

Monday, 16:30-17:30 - Virtual Room 21

Coralia Cartis

Stream: Plenaries
Plenary session
Chair: *Nikolaos Matsatsinis*

1 - Optimization for Data Science (Scalability and tractability challenges)
Coralia Cartis

Known by many names, sketching techniques allow random projections of data from high to low dimensions, while preserving useful properties. This talk explores ways to use sketching (and related techniques) as a powerful dimensionality reduction tool, to improve the scalability of algorithms for diverse classes of optimization problems and applications, from linear to nonlinear, local to global, derivative-based to derivative-free; global rates of convergence as well as numerical illustrations will also be given.

Monday, 17:30-19:00

■ MF-21

Monday, 17:30-19:00 - Virtual Room 21

Networking - career progression strategies

Stream: WISDOM Round Tables
Workshop session
Chair: *Renata Mansini*
Chair: *Paula Carroll*

1 - Networking - career progression strategies
Paula Carroll

The WISDOM Roundtable is a 1.5 hour panel discussion. The objective is to discuss networking as a strategy to help career progression and build personal influence, and to discuss how to manage work-life pressures. Panellists will be invited to discuss their experiences and make suggestions. Panellists will also discuss what they believe are appropriate metrics to measure impact in scientific and technical activities.

The WISDOM Forum are delighted to welcome panellists: Prof Ruth Misener (EPSRC Early Career Research Fellow); Dr Frances O'Brien (WISDOM Forum and UK OR Society WORAN); Dr Alberto Santini (EUROYoung); Prof Paolo Toth (former EURO president, and EURO Gold Medal winner); Dr Giovanni Felici (European Research Council representative).

Dr Paula Carroll (WISDOM Forum chair) will introduce the panel, Prof Julia Bennell (EURO VP2) will moderate the session.

■ MF-63

Monday, 17:30-19:00 - Virtual Room 63

Last minute changes 2

Stream: Last minute changes
Invited session
Chair: *Ramin Raeesi*

1 - A fast hybrid evolutionary algorithm for a bi-criteria moving target travelling salesman problem
Alaleh Maskooki, Kalyanmoy Deb, Markku Kallio

We propose a customized genetic algorithm (CGA) to find the Pareto-frontier of a bi-criteria model for a moving-target travelling salesman problem, where the number of targets as well as their location vary with time and can be defined arbitrarily. The problem of our interest arises from a real-world application of an autonomous control vessel measuring greenhouse gas emissions of ships navigating in the Baltic sea. Although the literature on dynamic TSP is vast, studies on moving-target TSPs are in early stages. We formulate the problem as a bi-criteria ILP model based on predicted trajectories of targets to get the optimal itineraries in the underlying dynamic network. Thereafter, to tackle the impracticality of ILP models on large-scale datasets, we propose the hybrid CGA method which combines a customized genetic algorithm with concepts from dynamic programming. CGA is a fast alternative to ILP solvers for finding the efficient Pareto-frontier. The NSGA-II is used as the non-dominated sorting method. Using real-world datasets for target trajectories, the performance of CGA is evaluated in comparison with ILP solutions in terms of accuracy and computational efficiency. Results over multiple runs indicate convergence to the efficient frontier with robustness and considerable computational speed-up compared to ILP solver. The solution provides decision support for the manager to choose the most favorable decision at the beginning of the planning horizon.

2 - Stochastic Job shop to minimize expected maximum lateness
Andrea Rivera, Ocampo María José, Gabriel Forero, Eliana Maria Gonzalez-Neira

We addressed a stochastic job shop problem (SJSP) that minimizes the expected maximum lateness. The problem considers deterministic processing and sequence-dependent setup times, and the stochastic events are machine breakdowns composed of two stochastic times: times between failures and times to repair. To solve the problem, we proposed a simheuristic approach that hybridizes a tabu search (TS) algorithm with Monte Carlo simulation. The problem was solved in three phases. Firstly, a mixed-integer linear programming model was designed for the deterministic counterpart of the problem. Secondly, the meta-heuristic TS was designed for solving large instances of the deterministic problem. Thirdly, the simheuristic was designed and compared to simulated solutions of mathematical model and simulated solutions of EDD dispatching rule. For the simheuristic phase times between failures and repair times followed exponential and log-normal distributions. We assumed that the processing is resumable after a breakdown occurs, i.e., the processing of a job continues after the repair of the machine, without loss in time. Results showed that the simheuristic improved the simulations of the mathematical model by 37% for 4x4 instances and 11% for 6x6 instances. Additionally, in comparison with the simulation of EDD dispatching rule for large instances, the simheuristic presents an average improvement of 28% for log-normal distribution and 10% for exponential distribution.

3 - Fuelling the zero-emissions road freight of the future: routing of mobile fuellers
Ramin Raeesi

The future of zero-emissions road freight is closely tied to the sufficient availability of new and clean fuel options such as electricity and Hydrogen. In goods distribution using Electric Commercial Vehicles (ECVs) and Hydrogen Fuel Cell Vehicles (HFCVs) a major challenge in the transition period would pertain to their limited autonomy and scarce and unevenly distributed refuelling stations. One viable solution to facilitate and speed up the adoption of ECVs/HFCVs by logistics, however, is to get the fuel to the point where it is needed (instead of diverting the route of delivery vehicles to refuelling stations) using "Mobile Fuellers (MFs)". These are mobile battery swapping/recharging vans or mobile Hydrogen fuellers that can travel to a running ECV/HFCV to provide the fuel they require to complete their delivery routes at a rendezvous time and space. In this presentation, new vehicle routing models will be presented for a third party company that provides MF services. In the proposed problem variant, the MF provider company receives routing plans of multiple customer companies and has to design routes for a fleet of capacitated MFs that have to synchronise their routes with the running vehicles to deliver the required amount of fuel on-the-fly. This presentation will discuss and compare several mathematical models based on different business models and collaborative logistics scenarios.

4 - Optimal bidding strategies of a microgrid in energy markets under uncertainty: A stochastic programming approach
Robert Herding, Wayne W. Jones, Emma Ross, Sam Johnson, Vassilis Charitopoulos, Lazaros Papageorgiou

Microgrids have become increasingly important as energy systems by shifting from centralised energy generation to a decentralised production through distributed energy resources, typically with high shares of intermittent renewables. Time varying electricity prices in short term energy markets can offer potential revenue streams for a microgrid through intelligent forecasting and operational decision making around its distributed energy resources. In the present work, we investigate optimal bidding strategies for a microgrid with different generation and storage technologies that participates in short-term energy markets. The overall problem is formulated as a mixed integer linear programming model. Finally, in order to hedge against the uncertainties present in the microgrid environment (e.g. day-ahead market price, load, renewable availability) we propose and test a stochastic programming framework. The effectiveness and computational efficiency of the proposed framework are demonstrated through a number of problem instances.

Monday, 19:30-21:00

■ MG-21

Monday, 19:30-21:00 - Virtual Room 21

Behavioral Modelling in Organization Studies

Stream: Behavioral Modelling
Invited session
Chair: *Stephan Leitner*
Chair: *Friederike Wall*

1 - Self-organized task-allocation and learning in organizations
Stephan Leitner

The allocation of tasks is a central element of organizational design. Following the classical organizational design approach, the formal characteristics of the tasks that organizations face are the basis for the ideal organizational structure that enables an organization to succeed. Often, however, the formal characteristics of tasks are hard to determine. The classical view also widely ignores that informal structures, such as social ties between individuals and socio-economic processes, might affect an organization's success, focuses on the organizational designer's role, and usually separates the design process from implementing organizational structures. We address these points of criticism and introduce an agent-based model of self-organized task allocation in organizations. We base the model on the NK-framework. The parameters N and K define the dimensions and complexity (the decision problem's formal characteristics), respectively. The N-dimensional problem is allocated to several agents endowed with the capability to learn about the decision problem's formal characteristics over time either by an individual reinforcement approach or by social learning. The management acts as a facilitator of the process. The results indicate that social learning is a key to efficient self-organized task allocation. Even if the formal characteristics are not entirely known, agents can self-organize in a structure that allows for high performance.

2 - Incomplete Incentive Contracting in Hierarchical Organizations: The Moderating Effects of Complexity
Friederike Wall

A large body of research examines how decision-making behavior in hierarchical organizations can be affected by incentive contracts such that the organization's overall objectives are achieved. For example, research inspired by agency theory focuses on incentive contracts to deal with moral hazard and adverse selection. However, there is considerable evidence that incentive contracts may be incomplete. Contractual incompleteness may be caused by contracting parties' limited cognitive capabilities, such as to foresee all future states of the environment or cover a manager's entire task with the contract. This paper addresses situations of the latter form in which incentive contracts govern only a part of decision-makers' task. In such a case, the principal has discretion over decision-makers' compensation related to the non-contracted parts of their particular tasks. Hence, trust in the principal becomes crucial for how much effort decision-makers allocate to the uncontracted part. An agent-based simulation using the framework of NK fitness landscapes is employed to study the effects of incomplete contracts in hierarchical organizations. The model controls for the complexity of the overall decision-problem to be solved collaboratively and for agents' information processing capabilities. The results suggest that complexity and information processing capabilities subtly interfere regarding managers' trust, their effort, and overall organizational performance.

3 - Multi-level adaptation of groups that solve complex tasks: An agent-based simulation.
Dario Blanco Fernandez, Stephan Leitner, Alexandra Rausch

Decision-makers often form in groups to solve complex tasks, such as consulting projects, disaster relief rescue operations, and construction work. Complex tasks (i) consist of several interdependent subtasks, and (ii) cannot be solved by an individual alone but need collaboration. Groups (such as virtual organizations or cooperatives) are often self-organized by different individuals and group members might change over time. According to previous research, the adaptation to complex task-environments is a key-characteristic of successful groups in terms of task performance. However, researchers have often studied adaptation from a unidimensional perspective by considering it as a learning process either at the individual or the group level. This approach ignores the potential interactions between the two adaptation levels. We, in contrast, employ an agent-based model that considers multi-level adaptation. At the individual level, agents adapt by discovery learning, and we implement adaptation at the group level as a recurring self-organizing process. For tasks characterized by a relatively low level of complexity, the results suggest that groups can achieve high task performance when individual learning and the groups' recurrent self-organization are strongly followed. Conversely, for more complex task-environments, moderate individual learning and moderately recurrent self-organization are associated with higher task performance.

4 - Behavioral modelling in management control: Agentization of the hidden-action model
Patrick Reinwald, Stephan Leitner, Friederike Wall

Management Science is concerned with many complex problems, such as the behavioral control of distributed decision-makers in the presence of information. The real-world issues at hand are often simplified to cope with their complexity. For example, the representation of human behavior in mathematical economic models often substantially differs from real-world behavior. In consequence, models might have a limited capacity to explain empirical phenomena. The hidden-action model introduced by Holmström includes such simplifying assumptions. It captures a situation in which an agent performs a task on behalf of the principal in the presence of information asymmetries. The model provides a behavioral control mechanism. We analyze the effects of assumptions about (i) the principal's and the agent's cognitive capabilities and (ii) the availability of information about the environment. We follow an agentization approach that transforms the closed-form hidden-action model into an agent-based model variant. While Holmström's hidden action model - by the assumptions incorporated - makes sure that the principal can immediately develop an optimal control mechanism, our model allows observing the emergence of such a control mechanism over time. In our analysis, we emphasize the effect of the refined assumptions by comparing the solution gathered from the agent-based model variant with the solution provided by Holmström's model.

■ MG-22

Monday, 19:30-21:00 - Virtual Room 22

Theory and methods for continuous bilevel optimization I

Stream: Bilevel Optimization
Invited session
Chair: *Alain Zemkoho*
Chair: *Patrick Mehlitz*

1 - Directional necessary optimality conditions for bilevel programs
Jane Ye

The bilevel program is an optimization problem where the constraint involves solutions to a parametric optimization problem. It is well-known that the value function reformulation provides an equivalent single-level optimization problem but it results in a nonsmooth optimization problem which never satisfies the usual constraint qualification such as the Mangasarian-Fromovitz constraint qualification

(MFCQ). In this paper we show that even the first order sufficient condition for metric subregularity (which is in general weaker than MFCQ) fails at each feasible point of the bilevel program. We introduce the concept of directional calmness condition and show that under the directional calmness condition, the directional necessary optimality condition holds. While the directional optimality condition is in general sharper than the non-directional one, the directional calmness condition is in general weaker than the classical calmness condition and hence is more likely to hold. We perform the directional sensitivity analysis of the value function and propose the directional quasi-normality as a sufficient condition for the directional calmness. An example is given to show that the directional quasi-normality condition may hold for the bilevel program.

2 - Asymptotic regularity for bilevel optimization problems
Patrick Mehlitz

It is well known that asymptotic (sometimes referred to as 'sequential') constraint qualifications are comparatively weak while playing an important role in the convergence analysis of several classes of solution algorithms in optimization theory. In this talk, we first discuss suitable notions of asymptotic stationarity and regularity for nonsmooth Lipschitzian optimization problems before applying them to the setting of bilevel optimization. Therefore, we make use of the popular value function reformulation. Some sufficient conditions for the presence of asymptotic regularity are presented. Furthermore, we comment on the relationship between asymptotic regularity and the popular partial calmness condition. The talk closes with some simple algorithmic consequences of this theory. Exemplary, we focus on penalty methods in bilevel optimization.

3 - A stochastic approach that solves the ambiguity of ill-posed bilevel games
Anton Svensson, David Salas

Ill-posed bilevel games are those in which the lower-level problem has more than one optimal solution to at least one upper-level strategy, making the upper-level problem ambiguous. To deal with this ambiguity, the classical optimistic and pessimistic approaches, which are the most common in the literature, make the extreme assumption that for each upper-level strategy, the lower-level chooses the most (optimistic) and least (pessimistic) favourable optimal reaction among all possible optimal reactions, respectively.

In this talk we revisit and generalize the so-called intermediate approach proposed by Mallozzi and Morgan which is based on decision dependent probability distributions that concentrate on the sets of optimal reactions. We provide an existence result for the intermediate approach, which is based on what we call the rectangular continuity of the set-valued map that defines the lower-level optimal reactions. Since the rectangular continuity coincides with usual continuity when the images has constant finite dimension, we extend previous existence results for intermediate bilevel games with regularized lower-level. But further we prove existence of solutions for non-regularized bilevel games for a particular intermediate belief which corresponds to uniform distributions over the optimal reaction sets, provided the lower-level problem is convex and weakly analytic.

4 - Gauss-Newton-type methods for bilevel optimization
Alain Zemkoho

We study Gauss-Newton-type methods for over-determined systems to find solutions to bilevel programming problems. To proceed, we use the lower-level value function reformulation of bilevel programs and consider necessary optimality conditions under appropriate assumptions. First, under strict complementarity for upper- and lower-level feasibility constraints, we prove the convergence of a Gauss-Newton-type method in computing points satisfying these optimality conditions under additional tractable qualification conditions. Potential approaches to address the shortcomings of the method are then proposed, leading to alternatives such as the pseudo or smoothing Gauss-Newton-type methods for bilevel optimization. Our numerical experiments conducted on 124 examples from the recently released Bilevel Optimization LIBrary (BOLIB) compare the performance of our method under different scenarios and show that it is a tractable approach to solve bilevel optimization problems with continuous variables.

The work is based on Joint work with Jörg Fliege and Andrey Tin (School of Mathematical Sciences, University of Southampton, UK).

■ MG-23

Monday, 19:30-21:00 - Virtual Room 23

Recent Advances in Derivative-free Optimization II

Stream: Derivative-free Optimization
Invited session
Chair: *Giampaolo Liuzzi*
Chair: *Ana Luisa Custodio*

1 - DGO: A DIRECT-type MATLAB Toolbox for Derivative-free Global Optimization
Linas Stripinis, Remigijus Paulavičius

Due to its simplicity and efficiency, the derivative-free global-search DIRECT(DIvide a hyper-RECTangle) algorithm has received great attention from the optimization community, and various novel ideas and extensions have been proposed. In this talk, we present the DGO, a new MATLAB toolbox for derivative-free global optimization. DGO is a collection of various deterministic derivative-free DIRECT-type algorithms for box-constrained, generally-constrained, and global optimization problems with hidden constraints. Each sequential algorithm is implemented in two different ways: using static and dynamic data structures for more efficient information storage and organization. Furthermore, parallel schemes are applied to some promising algorithms within DGO. The toolbox is equipped with a graphical user interface (GUI), which ensures the user-friendly use of all functionalities available in DGO. All these features are demonstrated in detailed computational studies using a created comprehensive library of global optimization test problems. Additionally, six classical engineering design problems are used to demonstrate the applicability of DGO to challenging real-world problems.

2 - Gradient and Hessian Approximation Techniques in Derivative-free Optimization
Gabriel Jarry-Bolduc, Warren Hare

In this presentation, derivative-free approximation techniques to approximate the gradient and the Hessian are discussed. Error bounds for the underdetermined, determined and overdetermined cases are provided. A novel Hessian approximation technique called the nested-set Hessian is introduced. It is proven that the nested-set Hessian requires (n+1)(n+2)/2 function evaluations to accurately approximate the Hessian and it is demonstrated how to build a minimal poised set for nested-set Hessian computation.

3 - Structured Derivative-free Optimization with Applications to Machine Learning
Andrea Cristofari, Francesco Rinaldi

In this talk, we consider structured large-scale black-box optimization problems arising in machine learning applications. We examine a tailored derivative-free approach that computes a solution in a reasonable amount of time with a limited budget of function evaluations. Some numerical results are presented and discussed.

4 - A New Derivative-free Interior Point Method for Constrained Black-box Optimization
Giampaolo Liuzzi, Andrea Brilli, Stefano Lucidi

Nowadays, black-box optimization problems are ubiquitous in many applications. This class of problems is characterized by objective and/or constraint functions that are only known through their input-output behavior, i.e. no analytical expression of the functions is available. Thus, typically, first order derivatives cannot be used or are, at the very least, untrustworthy. Such problems mainly arise in those contexts where the objective and constraint functions are computed by means of relatively complex and time-consuming simulators. Frequently in such applications, constraints are hard in the sense that functions cannot be computed (or they could not even be defined) outside of the feasible region. In such situations, it is customary to use an extreme or dead penalty approach in which an extremely high value is assigned to the objective function outside of the feasible region. In this way, if a feasible starting point is known, the algorithm remains trapped within the feasible region. However, such an approach frequently causes numerical difficulties which are basically due to the discontinuity of the objective function on the boundary of the feasible region. In this talk, we approach the problem with hard constraints by means of an interior log-barrier penalty function. We propose an algorithm model and study its theoretical convergence properties. Further, we also present preliminary numerical results which show viability of the proposed method.

■ MG-24

Monday, 19:30-21:00 - Virtual Room 24

Real Options

Stream: Optimal Control Theory and Applications
Invited session
Chair: *Peter Kort*
Chair: *Marta Castellini*

1 - Effects of Creative Destruction on the Size and Timing of an Investment
Anne Balter, Peter M. Kort, Kuno Huisman

In the current innovation-driven economy project lives are short due to the economic phenomenon creative destruction. This paper investigates its implications for optimal firm investments. We find that if the firm is a monopolist, a reduced length of the project life does not affect the size of the investment but the firm waits longer for better market conditions before it invests. If, in addition, the option to invest could also expire in finite time, the firm invests earlier and less. Besides a monopoly setting we also investigate a duopoly. An entry deterring incumbent invests in the same way as the monopolist except that the incumbent will invest earlier in a scenario where the investment option never expires. When, initially, firms are both potential entrants, the project life being finite reduces the incentive to preempt the investment of the opponent. Finally, we show that considerable value losses will be achieved when the project life being finite is mistakenly not taken into account in taking the investment decision. This value loss is enlarged by the preemption effect just mentioned.

2 - Optimal Randomization over Thresholds in an Abandonment Problem with a Spectrally Negative Levy Process
Jacco Thijssen, Laura Delaney

This paper considers an abandonment problem in which the underlying uncertainty over future demand is modelled as a spectrally negative Levy jump diffusion. We show that the solution to the corresponding optimal stopping problem may not be a threshold policy. We derive the conditions under the solution is a threshold policy and show these may fail when the jumps are large. In the latter case we show that the optimal abandonment strategy consists of randomizing over thresholds. As a result, abandonment may be optimal sooner than the classical solution implies.

3 - Going International to Shift Profits? A Real Option Approach
Nicola Comincioli, Paolo Panteghini, Sergio Vergalli

Debt shifting and transfer pricing allowing multinationals to shift debt and profit to benefit from favorable tax treatment are global phenomena extensively studied in literature. Research in this field focuses on (i) empirical approaches quantifying their benefit and evaluate the deterring effect of regulations' tightening; (ii) theoretical models describing the decisional process of multinationals choosing to exploit these practices.

Our study falls into the second category and aims to overcome the following limits that are currently poorly considered: (i) consider debt shifting and transfer pricing simultaneously; (ii) do that in a stochastic environment i.e. under default risk; (iii) study the real option of a domestic firm going international to exploit tax avoidance practices.

In the first part we evaluate if and when the decision is made, considering the costs and benefits of the viable tax avoidance practices. Then, we study the optimal level of tax avoidance and the implications in terms of capital structure. Finally we investigate the effects of this decision in terms of systemic welfare.

In the second part we present a set of numerical simulations based on the theoretical findings, to quantify the effects of exercising the real option on the one hand on the value of the company and on the other on the welfare of the system. Finally all these simulations are object of sensitivity analysis and comparative statics to study the impact of exogenous variables.

■ MG-25

Monday, 19:30-21:00 - Virtual Room 25

Stochastic Dual Dynamic Programming

Stream: Stochastic and Robust Optimization
Invited session
Chair: *Christian Füllner*
Chair: *Steffen Rebennack*

1 - Node Aggregation in Stochastic Dual Dynamic Programming
Renata Pedrini, Erlon Finardi, Felipe Beltrán

Stochastic dual dynamic programming (SDDP) is a well-consolidated methodology introduced in 1991 to solve the long-term generation scheduling of the Brazilian electrical power system. Mathematically, SDDP approximates cost-to-go functions (resultant from Dynamic Programming) using piecewise linear approximations, defined by cutting planes computed in solving Linear Programs (LP). It is generally agreed that SDDP can handle large scenario trees by combining decomposition and sampling. The main idea is to avoid using all scenarios, employing a small sample to significantly reduce the number of LPs solved in each iteration. Despite the recent advances in the SDDP, some modeling simplifications are always needed to allow its computational tractability. Thus, many improvements have been proposed since the advent of SDDP due to the extensive range of applications. In this setting, we propose a node aggregation for splitting the scenario tree into connected subtrees, whose subtree size is the focus of this talk. The node aggregation has already been implemented to improve the nested decomposition computational performance, presenting satisfactory results. The node aggregation SDDP is assessed in a long-term hydrothermal scheduling problem, represented via the multistage linear stochastic program, where 53 hydro and 30 thermal plants meet a power demand over a 5-years planning horizon.

2 - A dual SDDP algorithm for risk averse problem
Vincent Leclere, Bernado Freitas Paulo da Costa

Multistage stochastic linear programs are difficult optimization problem with a large set of application especially for energy management question. The Stochastic Dual Dynamic Programming (SDDP) is a popular algorithm to tackle such problems in risk neutral or risk averse settings. One of the drawbrack of the method is that, while it compute an exact lower bound it only estimate through simulation the upperbound. This is especially difficult for risk averse problem. Recently multiple authors have suggested to apply the SDDP algorithm to a dual problem, yielding an exact upper bound, in the risk neutral setting. In this paper, leveraging the theory of perspective functions, we obtain a dual SDDP algorithm for risk averse problem, shedding also light to the supporting probability measures.

3 - Aspects of SDDP and practice
Wim van Ackooij, Welington de Oliveira, Yongjia Song

In this talk we will discuss regularizing SDDP through the use of normal solutions. We will show how the ideas from level bundle methods can provide some enhancement to the basic SDDP scheme. We will also briefly mention the use of conditional cuts - an experimental device taking inspiration from approaches known in mathematical finance - which can be usefull to represent dependencies without increasing the dimension of the state vector. We will also discuss how SDDP is available in SMS++ and can be combined with other decomposition approaches.

4 - Non-convex Benders decomposition
Christian Füllner, Steffen Rebennack

We propose a new decomposition method to solve multistage non-convex mixed-integer (stochastic) nonlinear programming problems (MINLPs). We call this algorithm non-convex nested Benders decomposition (NC-NBD).

NC-NBD is based on solving dynamically improved mixed-integer linear outer approximations of the MINLP, obtained by piecewise linear relaxations of nonlinear functions. Those MILPs are solved to global optimality using an enhancement of nested Benders decomposition, in which regularization, dynamically refined binary approximations of the state variables and Lagrangian cut techniques are combined to generate Lipschitz continuous non-convex approximations of the value functions. Those approximations are then used to decide whether the approximating MILP has to be dynamically refined and in order to compute feasible solutions for the original MINLP. We prove that NC-NBD converges to an approximately optimal solution in a finite number of steps. By incorporating sampling, NC-NBD can be converted to an extension of stochastic dual dynamic programming (SDDP).

Computational results indicate that the decomposition approach is best suited for (stochastic) problems with many stages and a moderate number of state variables.

■ MG-26

Monday, 19:30-21:00 - Virtual Room 26

Software for LP, MIP, and ML

Stream: Software for Optimization
Invited session
Chair: *Timo Berthold*

1 - PaPILO: Parallelising presolving in Mixed Integer Programming
Alexander Hoen, Ambros Gleixner, Leona Gottwald

Presolving is an essential part contributing to the performance of modern MIP solvers. PaPILO, a new C++ library, provides presolving routines for MIP and LP problems. This talk provides insights into important design choices enabling PaPILO's capabilities, in particular regarding its use of parallel hardware. While presolving itself is designed to be fast, this can come at the cost of failing to find important reductions due to working limits and heuristic filtering. Yet, even most commercial solvers do not use multi-threading for the preprocessing step as of today. PaPILO's design facilitates use of parallel hardware to allow for more aggressive presolving and presolving of huge problems. The architecture of PaPILO allows presolvers generally to run in parallel without requiring expensive copies of the problem and without special synchronization in the presolvers themselves. Additionally, the use of Intel's TBB library aids PaPILO to efficiently exploit recursive parallelism within expensive presolving routines, such as probing, dominated columns, or constraint sparsification. Despite PaPILO's use of parallelization, its results are guaranteed to be deterministic independently of the number of threads available.

2 - HiGHS: beyond linear programming
Julian Hall

HiGHS is establishing itself as a popular open source repository of high-performance software for linear optimization. Initially written to solve linear programming problems using the dual simplex method, its functionality has expanded recently to cover mixed-integer programming and convex quadratic programming. This talk will discuss these developments, as well as looking the at the question of funding such high-performance open source software, and the value of developing it within an academic setting.

3 - Ecole: A Gym-like Library for Machine Learning in Combinatorial Optimization Solvers
Maxime Gasse, Antoine Prouvost, Justin Dumouchelle, Lara Scavuzzo, Didier Chételat, Andrea Lodi

In this talk I will present Ecole, a new library to simplify machine learning research for combinatorial optimization. Ecole exposes several key decision tasks arising in general-purpose combinatorial optimization solvers as control problems over Markov decision processes. Its interface mimics the popular OpenAI Gym library and is both extensible and intuitive to use. We aim at making this library a standardized platform that will lower the bar of entry and accelerate innovation in the field. Documentation and code can be found at https://www.ecole.ai.

4 - Crossover using a basis matrix from the splitting preconditioner
Aurelio Oliveira, Cecilia O. Castro, Manolo Heredia

The goal of this work is to provide a basis matrix computed by the splitting preconditioner for interior point methods to a crossover procedure. Both approaches, interior point and simplex method are combined to solve linear programming problems. The interior point methods are used in early iterations. The linear system solution is computed via the splitting preconditioner which has a basis as one of its components. That basis is used in the crossover procedure when the simplex method is activated near an optimal solution. In addition, a set of basic indexes is used to improve the crossover performance. Numerical experiments with large-scale linear programming problems show the eficiency of the proposed crossover approach.

■ MG-28

Monday, 19:30-21:00 - Virtual Room 28

Data Mining and Statistics

Stream: Data Mining and Statistics
Invited session
Chair: *Pakize Taylan*
Chair: *Ioannis Tsiligkaridis*

1 - Classification using a Projection Decision Tree Algorithm
Ioannis Tsiligkaridis

Classification is very significant for data analysis for extracting models with important classes. The purpose of this work is twofold; first, to present the Projection Algorithm (PA), a new Decision Tree (DT) Algorithm, needed for Random Forest (RF) classification and second, to make classification comparisons with Data Mining Algorithms; such as Support Vector Machine (SVM), Neural Networks (NN), Logistic regression (LREG). PA, a top-down DT inducer with the next splitting node criterion (CNSN), is presented based on the purity metric using conditional probabilities. There are two phases that are used; the root node discovery phase, and the branch selection phase. The PA is applied to both phases following a counting process. It avoids the repetition and replication that are disadvantages of a classical DT that can imped its accuracy and comprehensibility. In the ensemble methodology, a Random Forest (RF) with bagging can support the DT method for better accuracy. Adding more trees in the forest over a certain threshold does not improve accuracy. An RF can be created from the PA (PARF) with no DT disadvantages. For the NN, a collection of communicated units, the back propagation method is used. The SVM, which is competitive with the NN, and the LREG, a supervised learning algorithm, are also employed. Classification experiments with the predefined models are provided with promising PARF and SVM results.

2 - Interurban mobility modeling based on data learning: case of morocco

Mohamed EL Hadraoui, Fouzia Ghaiti

Nowadays, the strategic decision on mobility has become more and more complicated, in this case, with regard to investments and the choice between different types of transport infrastructure. This choice is linked to two major components, namely: the cost of infrastructure projects and the type of infrastructure suited to the planned travel needs. Thus, travel prediction is an important step in transport planning and policy making to appropriately meet the new demands of inter-urban mobility. This prediction will also contribute to the improvement of these public policies as well as to the implementation of adequate master plans for mobility. Given the progress made in machine learning and in particular for the development of many prediction models, qualified as very powerful, the use of these techniques to model the need for travel is not widely explored. The objective of this research work is to fill in this gap by proposing an advanced machine learning approach adapted to this problem. From a database of travelers, our contribution is to study the effectiveness of this data driven model, based on data learning, as a very powerful predictive model of interurban mobility in Morocco. Preliminary experimental results show that the approach adopted outperforms other classical models, based on data, and often used to deal with such a problem.

3 - Best Submatrix Selection for the Truncated SVD

Yongchun Li, Weijun Xie

Truncated singular value decomposition (SVD), the best low-rank matrix approximation, has been successfully applied to many domains such as manufacturing, biology, and healthcare, which often possess high-dimensional datasets. To enhance the interpretability of SVD, sparse SVD (SSVD) was introduced to select a submatrix of the original data matrix when performing the low-rank approximation. Different from the literature, this paper presents a novel SSVD model that can select the best submatrix precisely up to a given size and preserve the properties of vanilla truncated SVD. The SSVD model is shown to be NP-hard with a reduction to the well-known sparse PCA, which motivates us to study effective algorithms with provable performance guarantees. To do so, we first formulate SSVD as a mixed-integer semidefinite programming formulation, which can be solved exactly for small or medium-sized instances and is useful to evaluate the solution quality of approximation algorithms. We next develop three selection algorithms based on different selection criteria and two searching algorithms: greedy and local search. We prove the first-known approximation ratios for all the approximation algorithms and show that all the ratios are tight, i.e., we demonstrate that these approximation ratios are unimprovable. Finally, our numerical study demonstrates the high solution quality and computational efficiency of our approximation algorithms.

■ MG-29

Monday, 19:30-21:00 - Virtual Room 29

Intelligent Decision Methods

Stream: Intelligent Decision Methods
Invited session
Chair: *Evangelos Grigoroudis*

1 - Advanced rule-based approaches in customer satisfaction analysis: Recent development and future prospects of fsQCA

Evangelia Krassadaki, Evangelos Grigoroudis, Nikolaos Matsatsinis, Constantin Zopounidis

Customer satisfaction is assessed by various quantitative and qualitative methods. Several quantitative methods adopt a regression analysis procedure, including MCDA techniques. However, most of them are compensatory approaches, based on an additive model that assumes preference independence among customer satisfaction criteria. During the last years, several rule-based methods have been proposed in the customer satisfaction analysis problem. Such approaches do not assume an analytical aggregation formula, and thus they may offer an alternative in this problem. The fsQCA method, based on fuzzy set theory and knowledge-based rule systems, focuses on linguistic summarization of 'if-then' type rules and provides all necessary/sufficient combinations (rules) of satisfaction criteria, which lead to the output (overall satisfaction). In this context, the criteria constitute the input variables, while the presence of overall satisfaction is the desired outcome. The applicability is illustrated through a case study. The dataset is analyzed using the fsQCA method, and the results are compared with an additive value-based model (MUSA method). The results provide a more detailed and valid analysis of customer satisfaction data and indicate the complementary nature of the alternative approach. Finally, we discuss the potential future research efforts, given that rule-based approaches have gained increasing attention during the last years in analyzing customer satisfaction data.

2 - Social Media Data Mining for Sentiment Extraction

Nikolaos Doukas, Nikolaos Krystallis, Nikolaos Matsatsinis, Nikolaos Bardis

Social media are increasingly becoming the primary platform for sentiment expression and public discussion, across all layers of society. Using this information, leaders can obtain significant insight into the psychological processes that effect, and in many ways determine, the behavior of people and their response to significant events. This paper presents a study that aims to extract conclusions about the collective sentiment of the community, based on the texts posted on Twitter, using suitable data collection and processing. The results and the conclusions presented concern the period 2019 - 21 and are focused in the city of Athens, Greece. The analysis focuses on the processing phases of the connection with the social platform, the collection and normalization of data, the extraction of sentiment information based on the processing of Greek language postings and the visualization of the results. The processing is based on open-source software tools, adapted for the particular circumstances. Suitable schemes are proposed for the collection and storage of the postings, the extraction of the significant words, the matching of the multiple forms of the word in the Greek language with the ones available in a sentiment lexicon and the calculation of the scores related to the different sentiments. The results presented indicate massive coordinated changes in the scores for different feelings that occur simultaneously with significant events of the coronavirus pandemic.

3 - Model for selecting optimal churn avoidance actions in a financial institution.

Alejandro Mac Cawley, Martin Navarrete

We propose and validate a mathematical model to detect churn intentions on a financial institution and select an adequate avoidance action. To achieve this, for each customer we first determine a client's probability to move his portfolio to another bank. With this information, we determine a priority for the commercial actions to be implemented to the churner portfolio, in order to optimize the customer management and maximize the retained profitability. The model was tested in a local financial institution with over 150.000 operations. Results indicate optimal profitability was obtained managing the top 31% clients of the prioritized portfolio, with a retention rate of 30% of the month churn profitability.

4 - Decision Support System Applications (1980-2020). Classification and statistical analysis
Panagiotis Mallios, Nikolaos Matsatsinis

The main goal of decision support system applications (DSS), is to aid decision makers by collecting data and information into their structured environment, in order t take an optimal decision. They are developed to accomplish several tasks, that is, organize the overflow of data, knowledge and information, provide support to decision makers and illustrate their judgment and preferences. The purpose of the current survey is the categorization and classification of DSS applications according to specific criteria and finally their statistical analysis according to special characteristics that may have. This paper provides a review of DSS applications over the period (January 1980-December 2020). Six hundred and sixty published applications are identified.

Our purpose is to develop a holistic approach to decision support systems, with their entire evolution and development so far worldwide, in order to extract critical information and inferences that will lead to a better understanding of their function, implementation and overall utility. We aspire to inform researchers and practitioners about major historical tendencies, to compile a systematic reference for the extended literature on DSS applications, to demonstrate both interest and scope in practical research within DSS field and finally to give future directions towards new theoretical development.

Keywords: decision support systems, survey, classification, statistical analysis

■ MG-30

Monday, 19:30-21:00 - Virtual Room 30

Fairness and Game Theory

Stream: Mixed Integer Linear Programming
Invited session
Chair: *Margarida Carvalho*

1 - On Fairness and Implementability in Stackelberg Security Games
Victor Bucarey, Martine Labbé

In this article we discuss the impact of fairness constraints in Stackelberg Security Games. Fairness constraints can be used to avoid discrimination at the moment of implementing police patrolling. We present two ways of modeling fairness constraints, one with a detailed description of the population and the other with labels. We discuss the implementability of these constraints. In the case that the constraints are not implementable we present models to retrieve pure strategies in a way that they are the closest in average to the set of fairness constraints

2 - Optimal Capacity Expansion in the College Admission Problem
Federico Bobbio, Margarida Carvalho, Alfredo Torrico, Andrea Lodi

The college admission problem plays an important role in several real-world allocation mechanisms. In particular, the student-oriented deferred acceptance (DA) algorithm is known to produce a stable matching that is weakly preferred by every student. However, if an extra position is available in a single university, then a subset of the students would improve their allocations. This raises a natural question: To which universities should we allocate B extra positions in order to produce the best possible allocation for all the students? In this work, we study the expansion of the capacities in the college admission problem with strict and complete preferences. Our main contribution is twofold: first, we provide a theoretical understanding of the underlying mathematical structure of the problem; second, we propose an algorithmic approach to solve the problem optimally.

3 - New integer programming models for stable kidney exchage problem
Kseniia Klimentova, Péter Biró, Ana Viana, Virginia Costa, Flip Klijn, João Pedro Pedroso

In this work, we study the stable exchange problem, considered it in the context of Kidney exchange programs. The problem is defined on a directed graph where each vertex represents a pair of incompatible donor and patient. Outgoing arcs from a vertex point to those pairs, whose donors are compatible for this patient. Moreover, each patient has preferences over all compatible donors, defined by some medical reasoning (more/less compatible donor for a patients). Exchanges between several such pairs are organized in a way that all the patients get a kidney: in another words an exchange is a set of disjoint cycles. In a view of presence of preferences, a standard approach in the literature is to discard exchanges that can be blocked by a cycle. Specifically, a cycle blocks an exchange if each of the patient in the cycle is assigned to a strictly preferred donor. Similarly, a cycle weakly blocks an exchange if each of the patients in the cycle is assigned to weakly preferred donor and at least one of them is assigned to a strictly preferred donor. An exchange is called (strongly) stable if there exists no (weakly) blocking cycles. In our work we present integer programming formulations for the stable exchange problem considering two cases: when there exists a limit on the length of cycles in the exchange, and another when such limit is absent. We present the results of computational experiments on validation of models and comparison of their effectiveness.

4 - Individual fairness on kidney exchange programs
Margarida Carvalho, William St-Arnaud, Golnoosh Farnadi, Behrouz Babaki

Kidney exchange programs have been implemented throughout the world. They decide donors' swaps among incompatible patient-donor pairs with the aim of maximizing the patients' benefit. In this presentation, we provide empirical evidence on the existence of multiple optimal solutions. This opens the question on how to select among those solutions. Note that this is an important question to address since a patient being in a solution has a significant impact in their life. Thus, we devise a procedurally-fair solution selection framework. Our methodology requires the ability of randomly select KEP-optimal solutions; in other words, it demands a process to randomly select optimal integer solutions. We present a dynamic programming, an integer programming and a constraint programming based approaches for the full enumeration of optimal solutions. To scale our method, we present a column generation algorithm.

■ MG-31

Monday, 19:30-21:00 - Virtual Room 31

new frontiers in portfolio selection

Stream: Non linear optimization in finance
Invited session
Chair: *Luiz Teixeira*
Chair: *Lorenzo Mercuri*

1 - Efficient Portfolio Construction through Fuzzy Logic and Entropy Maximization
Milena Bonacic, Juan Perez, Héctor López-Ospina, Cristian Bravo

One of the most desirable features of an investment portfolio is high efficiency in the use of risk, i.e. achieve high investment return per unit of risk used. Having expected return of assets and covariance between assets, Markowitz theory is the best choice for construct efficient portfolios. However, problems arise when the time horizon of the investments is short (12-36 month) and realized return and covariance of different asset are typically far away from expected return and covariance. This paper explores a way to construct efficient portfolios through maximization of bi-objective function. One objective is to achieve maximum portfolio entropy, the other objective is to achieve through fuzzy logic, maximum entropic membership function for coefficients associated with return and variance. This study compares the results of Markowitz portfolios subject to ten different level of variance, maximum entropy portfolio subject to ten level of variance, fuzzy entropy portfolios and fuzzy bi-objective proposed in this study. Five different time windows from the year 2000 to 2020 for equities indexes were tested. Equities indexes used were, US, Europe, China and Japan. With historical average for return and covariance of assets as expected return and covariance of assets, were constructed optimal portfolios. Compounding returns of the five different periods for optimal portfolios, it was found high efficient portfolio for fuzzy bi-objective model validating this study.

2 - Robust parametric portfolio policies
Sandra Caçador, Pedro Godinho, Joana Matos Dias

In this work we apply the concepts of relative-robustness and absolute-robustness to parametric portfolio models. The portfolio weights are parametrized as functions of observable quantities. This contributes to the avoidance of estimation errors, also reducing the dimensionality of the optimization problem since the parameter space will only increase with the number of stock characteristics, rather than the number of stocks. The inherent uncertainty associated with portfolio optimization problems is still present, and this uncertainty justifies the use of robust optimization. The proposed relative-robust approach considers the minimization of the maximum regret, with regret being defined as what the investor loses by choosing a portfolio that is not the best one for the situation that came to occur. The proposed absolute-robust approach considers the usual analysis of the worst case scenario, maximizing the investor's expected utility in this case. The robust optimization models bring several computational difficulties, which justify the use of a genetic algorithm for defining the solution. Extensive computational experiments were performed. The performance analysis shows that the proposed robust parametric portfolios generally outperform the non-robust parametric portfolio policies as well as other robust and non-robust benchmarks used in this study.

3 - Cryptocurrency Arbitrage Opportunities in the Network of Crypto-Exchanges
Kristina Sutiene, Audrius Kabasinskas

Cryptocurrency arbitrage is a trading strategy of taking advantage of differences in cryptocurrency prices to make a profit. Using tick-level data from February 2018 through March 2020, we show that there exist recurrent arbitrage opportunities in the crypto-world, which is designed as the network of crypto-exchanges. As such, we focus on the aim to identify the best exchanges to buy crypto-currencies and then to sell them. Using graph-theory technique we estimate the importance of crypto-exchanges in the network, by assigning a particular role to the exchange in generating the arbitrage opportunities. In addition to typical network centrality measures, we propose an arbitrage ratio, which is frequency-based network measure to describe the role of crypto-exchange. Finally, we explore how the price-changes of crypto-currencies contribute to the arbitrage opportunities by means of canonical correlation.

4 - Spread Option Pricing in a Copula Affine GARCH(p,q) Model
Lorenzo Mercuri, Edoardo Berton

In this study, we construct a bivariate market model combining the copula function with the affine GARCH(p,q) process used to describe the marginal dynamics of the log-price. We then provide a numerical procedure for pricing European spread option contracts. To assess the accuracy of our approach we present a comparison with the Monte Carlo simulation method.

■ MG-32
Monday, 19:30-21:00 - Virtual Room 32

Multicriteria Decision Aid Applications

Stream: Multiple Criteria Decision Analysis
Invited session
Chair: *Athanasios Spyridakos*

1 - Evaluation of agricultural management alternatives using MAUT/WAP and UTA methods
Isaak Vryzidis, Alexandros Psomas, Athanasios Spyridakos

Agricultural management problems can be associated with multiple objectives, including those related with the management of water quantity, water quality, soil, energy and food production. Furthermore, specific management schemes have important economic dimensions, such as the required investments for their implementation. Decision making in this context has significant synergies and trade-offs. In this work, we describe a specific agricultural management problem from central Greece, and we demonstrate the use of two different Multi-Criteria Decision Aid (MCDA) methodological frameworks. The first MCDA framework follows a disaggregation-aggregation approach utilizing the UTA method with strength of preferences. The process is based upon an interview with an expert decision maker and the elicitation of his preferences for the prioritisation of a reference set of unnamed alternatives. The second MCDA framework follows a Multi-Attribute Utility Theory (MAUT) approach. Marginal value functions are estimated for selected named criteria with the support of the Multicriteria Interactive Intelligence Decision Aiding System (MIIDAS). The weights of selected named points of view and criteria are also estimated following the Weights Assessment through Prioritisation method (WAP). The MAUT-WAP framework is applied through an interactive session with an expert decision maker. The findings from the demonstration of both MCDA frameworks are presented, compared and discussed.

2 - Designing and testing the IMPACT HTA socio-technical framework to assist HTA agencies in the multicriteria evaluation of new medicines on a common basis
Monica Oliveira, Teresa Cipriano Rodrigues, Liliana Freitas, Ana Vieira, Klára Dimitrovová, João Bana e Costa, Aris Angelis, Panos Kanavos, Carlos Bana e Costa

When evaluating medicines, Health Technology Assessment (HTA) committees consider multiple value dimensions, variable quantity and quality of evidence, as well as make use of their qualitative knowledge regarding medicines' impacts; and at the top level, HTA agencies face the challenges of promoting consistency in medicines evaluations across committees and of finding a balance in the involvement of HTA stakeholders and experts in evaluations. In this study we describe the development and testing of the IMPACT HTA socio-technical framework to assist HTA agencies in valuing medicines in multiple dimensions across diseases on a common basis. Technically, the framework combines MACBETH with concepts of the swing weighting matrix so that a common value frame is set by the HTA agency for groups of therapeutic indications, and committees evaluate medicines on a structured basis and departing from the value set defined by the agency. Socially, the framework is developed through a collaborative modelling approach in which key HTA stakeholders and members of evaluation committees are involved in a sequence of Delphi and decision conferencing processes so as to develop both the value frame for each therapeutic indication, and MACBETH value models for specific medicines' evaluations. Results from testing the HTA framework in case studies developed in two HTA agencies from Belgium and Sweden are presented, and feedback and insights from participants about the framework are provided.

3 - Multivariate statistical Modeling of Housing Unit Price to Validate the Government Estate Control Policy in Beijing, China
Chi-hong Ho, Chi-Feng Ho

After the Worldwide Housing Bubbles, Chinese estate prices had grown too fast, which has become one of the best targets for investment. The Chinese Authorities stated the Estate Control Policy in 2016. The idea of this policy would help to control house prices and provide more people to buy their own house without that much money. China had focused on developing sophisticated technology for the national strategy of improvement. Some famous IC semiconductor companies established factories and industries in Yizhuang. Author's purpose: real estate is a lower-risk investment in Beijing, so the authors want to use statistical models to find out whether there is an opportunity to earn money by investing in the estate. The authors used the Cluster sampling method to focus on one house community in Yizhuang. All of the house prices information that authors collected in the specific house community between 2019-2021. After the authors used the Z-Standardization to an equal weight of every raw data, the authors used lots of outlier detection tools to detect the critical house unit prices sold in the last two years, such as the Dixon Q test, Grubbs Outlier Test, Quantile Range Outlier, Robust Fit Outliers, and the Hotelling T2 distribution. The authors separated the houses into six different groups by layers and the house areas. Hence, the authors used the one-way ANOVA and match pair t-test to find the difference of unit price in different layers & different housing areas.

4 - MCDA-ULaval software for ELECTRE methods - Application to water source protection

Irene Abi-Zeid, Ariane Marais

We present MCDA-ULaval, a multicriteria decision analysis software for ranking and sorting, developed at Laval University, Quebec, Canada. The user-friendly tool is implemented in Java, which makes it easily portable. MCDA-ULaval implements a subset of the ELECTRE outranking methods including ELECTRE III (for ranking), and ELECTRE Tri B, ELECTRE Tri-C, ELECTRE Tri-nC (for sorting), with and without interaction. Variable thresholds are implemented for cardinal and ordinal criteria. Furthermore, stability analysis and scenario analysis are among the features available. MCDA-ULaval comes with a user guide and a few projects based on examples taken from the literature. The software is available for download at no charge, for research and teaching purposes, at: http://cersvr1.fsa.ulaval.ca/mcda/ and has been used for applications in Germany, France, Italy, Portugal, Greece, United Kingdom and Canada. We illustrate the use of MCDA-Ulaval on a project related to drinking water source protection conducted for the City of Québec using ELECTRE III and ELECTRE Tri-nC. We highlight some of the difficulties related to the use of ordinal methods in a real life project.

■ MG-33

Monday, 19:30-21:00 - Virtual Room 33

Multicriteria decision support systems

Stream: Multiple Criteria Decision Analysis
Invited session
Chair: *Athanasios Spyridakos*

1 - Utilising the System Thinking approaches to Multicriteria Decision Aid Processes

Konstantina Theona, Athanasios Spyridakos

This research work constitutes the results of the efforts to incorporate system dynamics approaches to the Multicriteria Decision Aid processes. The research focuses on the Initial steps of Multicriteria Decision Aid processes and more specifically in the intelligence phase, where the context and the criteria of each decision problem and the evaluation of the alternatives on the criteria, are identified. An extensive literature review of the above-mentioned approaches revealed a lack of a structured methodology on the criteria modeling stage of MCDA. The objective of this research is, to develop an integrated methodological tool based on systemic thinking for the identification of the criteria in every decision problem, by combining the methodological tools of System Thinking and the principles of Multicriteria Analysis. The embedding of the theory of constraints and the techniques of Archetypes as well their contribution in the intelligent phase of the Decision Making is discussed extensively in this paper. A representative example is used in order to illustrate the proposed methodological approach for the Intelligent phase of the Decision Making process.

2 - Combining recommender systems with multicriteria decision support to facilitate optimal course selection by learners - The QualiChain project's case

Vagelis Karakolis, Panagiotis Kapsalis, Christos Kontzinos, Stavros Skalidakis, Vasiliki Vlachou, Panagiotis Kokkinakos, Ourania Markaki, John Psarras

Nowadays, labor market is changing more rapidly than ever, especially for the technology sector. In contrast, universities are struggling to follow the pace of the labor market's evolution. This fact contradicts with the goals of university students that intend to select courses that will help them advance their careers, by following the updates of the labor market needs. Thus, the decision of selecting courses is important and difficult for students. On the one hand the skills taught to them significantly impact their future career; and on the other, selecting suitable courses requires considerable effort by a learner to find out which skills are highly demanded by the labor market, and which courses teach such skills.

This publication presents the work conducted to bring higher education closer to the labor market's needs by facilitating optimal decision making for learners, under the context of the EU funded project QualiChain. It presents, shortly, the QualiChain Recommender, a tool that suggests courses based on the labor market needs and the user's educational profile, as well as QualiChain MCDSS tool suite which enables users apply several multi-criteria decision support methods, to select the optimal decision according to their objectives. Afterwards, it presents how Recommender Systems and Multi-Criteria Decision Support can be combined to facilitate optimal selection of university courses, alongside real examples from the QualiChain platform.

3 - Impact and Degree of Utilization of Imprecise Information in MCDM-Support-Systems

Mendy Tönsfeuerborn, Rüdiger von Nitzsch

In a rational multi-criteria decision-making process using the multi attribute utility theory the decision maker has to define the quantitative parameters probabilities, utilities and attribute weights, in order to find the best alternative. However, it is often difficult to determine these parameters precisely. In order to support the decision maker, the approach of partial, imprecise, or incomplete information is used in literature. This approach is for example applied in the decision support system ENTSCHEIDUNGSNAVI to simplify the determination of the parameters. In this tool, which is also a decision skill training webtool, the decision maker can make use of imprecise information in three categories: regarding probabilities, utilities and attribute weights. In this paper, we analyze how to deal with imprecise information in MCDM-Support-Systems. Therefore, we analyze about 1500 real-world applications in the ENTSCHEIDUNGSNAVI in a) how often is imprecise information used, b) how helpful find the participants the usage of imprecise information and c) which impact does imprecise information in the three categories have on the final ranking of alternatives, especially, how stable is the position of the best alternative by using Monte-Carlo-Simulations. Furthermore, we give recommendations for the implementation of imprecise information in practice.

4 - PROMETHEE-Cloud: A Web-based implementation of the outranking method PROMETHEE

Erik Pohl, Jutta Geldermann

PROMETHEE (Preference Ranking Organization Method for Enrichment of Evaluations) is an outranking method for multi-criteria decision problems with a discrete set of available alternatives and criteria that has been introduced in 1985/86. Prominent applications with respect to PROMETHEE include environmental decisions-making, water management, and energy management. The method allows for an extensive analysis of the decision problem by means of three outranking flows, sensitivity analysis, and principal component transformations (i.e. the GAIA plane). Well known software implementations include Visual PROMETHEE, Decision LAB 2000, PROMCALC and D-Sight, which offer various decision analysis functions based on the PROMETHEE flows and additional methods for sensitivity analysis. In this talk, we introduce PROMETHEE-Cloud, a web-based implementation of the method with a wide range of sensitivity analysis features, which offers a modern, intuitive, and effective visual representation of the decision process and its results. The main functionality is presented by means of an illustrative example that include a weight sensitivity analysis and a Monte-Carlo simulation on the alternative's performance values and criteria weights.

■ MG-34

Monday, 19:30-21:00 - Virtual Room 34

Integrated problem settings I

Stream: Combinatorial Optimization
Invited session
Chair: *Stefan Voss*
Chair: *Gustavo Gatica*

1 - Two-stage VND for an industrial scheduling problem
Quentin Perrachon, Alexandru Olteanu, Marc Sevaux

In the context of the industry of small and middle-scale manufacturing, the process of optimized scheduling decision-making is not yet widely spread despite the large gains that may be achieved through a better scheduling of operations inside the workshop. We focus on batch production systems where the problem is modeled as a Job Shop and both the machines and the operators are considered as flexible resources. Resources flexibility and multiple resources requirements are the two main constraints we can find in an industrial context. However, resource availability and precedence constraints can be also considered. We are working on a problem with multiple objectives, such as lateness as one of the main objectives but also earliness, waiting time between operations, or the number of jobs in process at any time. We decompose the problem into three sub-problems: resources assignment, operation sequencing and finally operation timing. The approach consists in a cyclic two-stage variable neighborhood descent around the first two sub-problems. We additionally consider a data-driven approach in order to improve and better guide the VNDs.

2 - Solution approaches and managerial insights for truck and drone systems in last mile logistics
Maurizio Boccia, Adriano Masone, Antonio Sforza, Claudio Sterle

Last mile logistics (LML) is one of the most important and expensive part of the freight distribution process in a supply chain. LML role is not going to change in the future since we are observing an always increasing shift away from physical stores to digital shopping. In this context, the integration of new distribution technologies in the delivery systems, specifically drones, has been investigated by several companies to reduce the LML costs. The most promising delivery system, in terms of emissions and completion time reduction, consists of a truck and a drone operating in tandem for the parcel delivery to the customers. These new drone-based delivery systems have led to the definition of new and complex decision and optimization problems for which operations research methodologies represent a valuable support tool. In this context, several contributions have appeared in the last years providing ILP and MILP formulations for these kinds of problems. Nevertheless, these formulations suffer from dimensional drawbacks which make their solution impracticable even on small instances. In this work, we discuss exact and heuristic approaches for specific variants of the problem, and we provide a computational study on literature instances aimed at determining features characterizing good/optimal solutions. These features can be used both to decompose or reduce the size of the addressed problems and to derive managerial insights on this kind of distribution system.

3 - A column generation approach for solving the integrated timetabling and vehicle scheduling problem
Lucas Mertens, Bastian Amberg, Natalia Kliewer

Whereas operational planning problems are historically solved sequentially, steadily evolving solution approaches, supported by modern information technology, lead to new possibilities to provide integrated methods for solving planning-related decision problems. In our study we focus on the first two steps of the operational public transport planning: the timetabling (TT) and vehicle scheduling problem (VSP). Aiming to meet the passenger demand and high service standards, the TT takes among other the route structure and desired headways in consideration and results in a set of trips and scheduled times at stopping points. Given this timetable, the VSP is concerned with minimizing the costs for the utilization of vehicles serving each planned service trip. Traditionally, the TT is computed first and is used as an input to solve the VSP. However, already minor adjustments in the TT might lead to less operational costs in the scope of solving the VSP, while maintaining the quality of the timetable itself. We propose an integrated solution approach solving the TT and VSP. To achieve acceptable computational times, we construct a Time-Space network given an extensive, redundant list of possible service trips, and apply a column generation technique. The results are evaluated regarding to operational costs and estimated passenger satisfaction compared to state-of-the-art sequential solution approaches.

4 - Location of logistic platforms and routing of pineapple collection
Gustavo Gatica, Jua-Sebastián Arbelaez, Rodrigo Linfati, Daniel Rodriguez, David Álvarez-Martínez

A solution based on optimization and computational simulation models for the location of industrial management platforms for pineapple cultivation in Colombia is presented. The methodology considers three phases. The first phase generates the potential supply employing official information on product zoning by suitability and productivity. In the second phase, the transfer point of the perishable product and the times of the links in the value chain are determined by a computational simulation model. A mathematical optimization model for localization is proposed in the final phase, establishing if the time coverage is feasible and efficient. The possible economies of a model for stockpile routing, which considers potential customers and logistic platforms, are studied using a metaheuristic Tabu Search algorithm. The proposed methodology uses official information on time, speed, production capacity, georeferenced aptitude information, spatial, economic, and land performance. The proposed tool is validated through scenarios, especially for the current situation of pineapple exports from the country. The scenario obtained by the methodology is consistent with the different logistics platforms already established. The metaheuristic presented to find economies in stockpiling was validated using classic instances from the literature, showing acceptable behavior and, in some cases, outperforming the best solutions presented in the literature.

■ MG-35

Monday, 19:30-21:00 - Virtual Room 35

Optimization Advances with Quantum Applications I

Stream: Combinatorial Optimization
Invited session
Chair: *Fred Glover*
Chair: *Gary Kochenberger*
Chair: *Yu Du*

1 - Mathematical programming formulations of the perfect vertex and edge domination problem
Said Hanafi, Vinicius L. Do Forte, Abilio Lucena

A set of vertices or edges is a dominating set in a graph if every element not in the dominating set is adjacent to one or more elements in the dominating set. The concept of domination in graphs has been extensively studied and has many applications. A subset of vertex or edges is a perfect dominating set if every element not in it is adjacent to exactly one element in it. In this paper, we propose several new mathematical programming formulations for the perfect dominating problem. First, a quadratic formulation with only binary vertex or edge variables is proposed for the vertex or edge perfect dominating set problem. Exploiting the link between vertices and edges, quartic, cubic and linear models are also introduced. Moreover, we propose an exponential number of mixed integer programming formulations based on the subset of binary variables S relaxed to be continuous. The size of these models (number of variables and of constraints) depends on the number of vertices, the number of edges and also the first Zagreb index of the subgraph induced by S. The proposed mixed integer programming formulations are tested on some class of graph recognized to be NP-Hard for the perfect dominating problems. Nine mixed integer programming formulations are implemented and compared in terms of the quality of the upper bounds and the CPU time consumed by CPLEX solver using the 3-regular graphs, bipartite graphs, hypercube graphs and queen graphs as instances.

2 - Using the QUBO model to Solve Large Set Partitioning Problems.
Gary Kochenberger, Fred Glover

The QUBO model has emerged as a unified modeling and solution framework for a large variety of combinatorial optimization problems. Given a classically formulated combinatorial optimization model, an equivalent QUBO model can be formulated by representing constraints as penalties to be appended to the originally objective function. Interest in this approach has grown substantially in recent years due to developments in the quantum computing community since their solvers are restricted to solving QUBO models. In this talk we investigate the QUBO approach for solving large set partitioning problems. Computational experience is given providing a comparison with AlphaQUBO, a modern metaheuristic QUBO solver running on conventional computers, and a leading quantum QUBO solver based on quantum annealing. Comparisons are also made with CPLEX to provide another benchmark for the problem considered in this study.

3 - Discrete diversity and dispersion maximization
Anna Martínez-Gavara, Rafael Marti

Diversity or dispersion maximization consists in selecting a subset of elements from a given set in such a way that the distance among them is maximized. There has been a growing interest in these problems in the last 30 years, and several models have been proposed to reflect the notion of diversity and dispersion depending on the specific practical application. These models have applications in workforce management, ecological preservation or location problem, among others. The literature in diversity problems, closely link to location models, is vast and includes many solution methodologies, from simple heuristics to complex metaheuristics. These problems are still developing and exhibit a huge potential in new areas, such as those including side constraints, that deserve the attention of researchers in optimization.

In this talk we review the different mathematical models and discuss the metaheuristic methodologies proposed to deal with them. Starting in the late eighties, when the first models were proposed, we identify three periods of time. The critical analysis from an Operation Research (OR) perspective of the previous developments, permits us to establish the most appropriate models, their connection with practical problems in terms of dispersion and representativeness, and the open problems that are still a challenge.

■ MG-36

Monday, 19:30-21:00 - Virtual Room 36

Medical Supply Chains and Decision Making

Stream: ORAHS: OR in Health and Healthcare
Invited session
Chair: *Joe Viana*

1 - Optimising preventative care decision making of coronary heart disease using Decision Programming
Helmi Hankimaa

The current policy for providing preventative care for coronary heart disease (CHD) could arguably be seen as unsuccessful as the majority of CHD events occur in the population that is not receiving preventative treatment. Treatment is administered based on a patient's estimated risk of suffering a CHD event. The genetic risk score was developed to improve CHD risk stratification. However, it is more expensive than traditional tests and thus, cost-benefit analysis is needed to evaluate its value in preventative care decision making of CHD.

The recently developed Decision Programming framework combines aspects of stochastic programming and decision analysis. In the framework, an influence diagram representation of the problem provides the basis for the optimisation problem formulation. This problem structure allows modeling multi-staged decision processes with discrete decision alternatives, endogenous uncertainties and multiple objectives.

In this study, an optimal decision strategy for allocating preventative care for CHD was developed using Decision Programming. The framework allowed for the intuitive modeling of the multiple testing and treatment decisions needed to estimate the patient's risk and administer treatment. It also allowed modeling the endogenous uncertainties of the testing decisions affecting the patient's estimated risk. The resulting strategy uses both traditional and genetic testing and achieves better cost-benefit outcomes than current policies.

2 - Experimental comparison of algorithms for features selection in machine learning applied to medical data
Thibault Agondja, François Delbot, Jean-François Pradat-peyre

Amyotrophic Lateral Sclerosis, or more commonly known as Charcot's disease, is a neurodegenerative disorder for which there is currently no cure. The median life expectancy at the onset of symptoms varies between 3 and 5 years. Establishing a reliable prognosis is a major challenge since it conditions the patient's management and quality of life.

The classification of patients, allows individuals to be grouped according to their needs and thus to adapt the patient's treatment in a more relevant way. The recent availability of ALS patient data for research has allowed the study of different prognostic and classification models. Some machine learning methods have been successful in exploiting the correlations present in the data to better understand the progression of the disease.

The amount of information present for each patient may disturb the machine learning since some data are not relevant. A features selection has to be performed. The selection of the most relevant features is an NP-hard problem. It is therefore unlikely to find an efficient algorithm that returns the best set of features to maximize the predictive quality of the model.In this work, we perform an experimental comparison of the most used heuristics (genetic algorithms, particle swarm etc.) in order to determine the best subset of features.

Our results allow us to eliminate some non-performing heuristics. We apply our methodology on benchmarks, and we obtain better results than in recent works.

3 - Multicriteria Classification of Inflammatory Bowel Disease patients
Thomas Xenos

IBD is a complex, multifactorial disease with diverse spectrum of symptoms, signs, lab, endoscopic and radiologic findings. However, current classification and scoring systems entail great degree of uncertainty in diagnosis, management unto proper treatment options. Herein lies a need to provide classification of patients subject to heaviness of incidents, high-mid-low, separating each case as persistent-intermittent-recurrent, extracting transitions from recession to high risk and vice versa, monitoring fluctuations. In this context, we analyse data to classify patients based on ordinance layout, relying on recurrence risk assessment criteria. Performing this task, we handle methods that outstretch from data mining, association rules, clustering and regression analysis to pattern recognition and classification techniques, leverage ample perspectives. As an amalgam, we may utilize multicriteria UTA family methods to classify patients in categories and oversee misclassifications. The outcome identifies patients at stake, proposing consistent ranking whilst accompanied by corresponding adjusted medication, mostly biologics. Thus, short-term goal encapsulate resilience against disease outbursts, whilst attain mid to long-term objective, i.e. maintain robustness of optimal pharmaceutical treatment. So, focusing on aggressive front-loaded medication we seek to aid doctors implement informed, evidence based decisions preventing irreversible conditions emphasising in care continuum.

4 - Medicine supply chain resilience: A hybrid simulation cost effectiveness analysis study of disruption intervention strategies

Joe Viana, Marianne Jahre, Kim van Oorschot, Christine Årdal

Medicine supply chains (MSCs) are complex systems. Effective treatment and management of many conditions requires the timely administration of genuine medications at the correct dose. Inadequate, missed, or delayed treatment can lead to poorer patient outcomes, including death, and result in more costly outcomes for the wider health system and society.

Potential reasons for shortages in MSCs include manufacturing issues, commercial withdrawal, drug recalls and quality issues, availability of raw ingredients, increased demand, distribution problems. These factors can occur in isolation or in combinations which can exacerbate disruptions due to the interconnectedness of the supply chain. Other factors of note: concentration of medicine production, Covid-19 disruptions of supply chains, and the impact of BREXIT.

Which factors make MSCs more resilient/viable in what contexts? From a whole system perspective (each echelon of the supply chain), how cost effective are the existing and proposed medicine supply chain disruption intervention strategies for selected case medicine(s)?

To explore the effects of MSC disruptions and how to mitigate them, simulation modelling is used to quantify disruption effects. A hybrid (ABM-SD-DES) simulation model of the MSCs of selected drug classes from a Norwegian context is currently under development. The model captures the required complexity exhibited by the system and draws upon Supply Chain Risk Management concepts.

■ MG-37

Monday, 19:30-21:00 - Virtual Room 37

Routing under uncertainty I

Stream: Routing, Logistics, Location and Freight Transportation
Invited session
Chair: *Maryam Darvish*

1 - Stochastic Vehicle Routing Problem with Multiple Vehicles: A Decentralized Approach

Mohsen Dastpak, Fausto Errico

In this talk, we focus on a version of the Vehicle Routing Problem (VRP) where customers' presence and demand are stochastic. In particular, we assume that the fleet of vehicles must complete the service within a given time limit. The objective is to maximize the served demand while respecting the vehicle capacities. We call this problem the VRP with Stochastic Customers and Demands (VRPSCD). Different from most of the literature related to the VRPSCD, we propose a decentralized decision-making framework where vehicles autonomously and dynamically plan their routes, according to the information revealed during operations. We formulate the problem in terms of a Markov Decision Process (MDP). In this context, the decentralized framework enables the possibility to suitable aggregate both state and action space, resulting in a more tractable problem. To solve the VRPSCD, we develop a Q-learning algorithm where value functions are implemented as a deep-neural network. Results demonstrate that our method significantly outperforms two commonly used heuristics for VRPSCDs. Moreover, we show that our approach can compete with methods proposed for the VRP with Stochastic Demands (VRPSD) as a specific version of VRPSCD. At last, the robustness of our approach regarding various alterations in the problem's characteristics is examined.

2 - Vehicle routing with due dates and stochastic release dates

Maryam Darvish, Leandro Coelho, Gilbert Laporte

In most variants of the VRP, static and deterministic situations are considered, whereas, in many real-life applications, information is not available in advance, but it is revealed at the time of planning. In this talk, we discuss a variant of the vehicle routing problem (VRP) in which the delivery may occur between a release and a due date. However, the delivery is conditioned on the availability of the product at the supplier. The due dates are pre-specified by the customers but the availability of the product at the supplier, which we consider to be stochastic, determines when, and if, a product could be delivered to the customers. The objective is to satisfy the demand of customers before a pre-specified due date with the least routing and penalty costs. We propose and compare several policies for this problem and solve instances of the problem under the presence of each policy.

3 - Robust algorithms for the two-echelon location routing problem under demand uncertainty

Ousmane Ali, Jean-François Côté, Leandro Coelho

We study the two-echelon location routing problem (2ELRP) where the demands of the customers at the second echelon are random variables and design a two-echelon distribution network where the opened depots and satellites have enough capacities to handle the variation of the demands, whereas the planned routes are feasible for all values taken by the demands within an uncertainty set. We propose a mathematical formulation for this uncertain problem and solve it through the robust optimization framework. We implement a Branch-and-cut algorithm to solve the integrated problem. We also design four sequential solution approaches based on the robust counterparts for the vehicle routing problem, facility location problem, location routing problem, and multi-commodity facility location problem.

4 - The robust vehicle routing problem: a novel commodity flow formulation based on the linearization of recursive equations

Rafael Campos, Pedro Munari

When dealing with logistical problems, companies usually face some level of uncertainty in parameters, such as travel time and demand, during their planning phase. Despite this being a common occurrence in practice, most of the literature still focus on deterministic variants. Robust optimization (RO) is an approach that incorporates parameter uncertainty into optimization models. In the context of vehicle routing problems (VRPs), RO results in more realistic routes, with higher chances of remaining feasible when executed in practice. The main advantage of the RO is not requiring the choice of a probabilistic distribution to model the uncertain parameters, something usually difficult to do in practice. We propose a novel compact formulation based on commodity flow constraints and develop a tailored branch-and-cut method for robust variants of traditional VRPs, namely, the capacitated VRP (CVRP) and the VRP with time windows (VRPTW). To obtain the robust counterpart of these formulations, we use the linearization of recursive equations, a technique recently proposed in the literature that leads to equivalent and more effective models when compared to the commonly used dualization scheme. We present the results of computational experiments using benchmark instances of the CVRP and VRPTW and analyze the performance of the proposed approaches with respect to the performance of other compact formulations as well as tailored exact methods.

■ MG-38

Monday, 19:30-21:00 - Virtual Room 38

Advances in Blood Supply Chain Management

Stream: ORAHS: OR in Health and Healthcare
Invited session
Chair: *Melanie Reuter-Oppermann*

1 - An optimization approach for tactical collection and production planning in the blood supply chain
Maria Meneses, Ana Paula Barbosa-Póvoa, Daniel Santos, Inês Marques

Collection plays a critical role in the blood supply chain as blood is a limited resource that can only be obtained from donors. Also, it is the foundation to produce the necessary blood products. Given their perishability, production should closely mirror demand requirements to guarantee an adequate supply and avoid wastage. Such planning activities are subject to uncertainty, which adds complexity to the management of the blood supply chain. To deal with the stochastic environment whilst keeping the desired service level, it is of utmost importance to develop appropriate tools to address mid-term collection plans coupled with production balancing requirements that achieve some balance between shortages and wastage. To that end, this work presents an optimization model for collection and production of blood products at the tactical level, under supply and demand uncertainties. The proposed model considers an established blood supply chain with multiple facilities, which constrain the collection and production strategies by the limited personnel and resources capacity of the network. So, the model also optimizes the available resources. Besides, the donor pool available and respective allocation to different collection methods is addressed. A case study of a blood supply chain is used to validate the proposed model and the performances of the proposed approach against the current practice are compared.

2 - Optimisation of platelet inventories in the Finnish Blood Service
Mary Dillon, Eeva Vilkkumaa, Fabricio Oliveira

Managing blood product inventories can be challenging due to stochastic supply and demand, varying shelf lives of the products, and the need to account for multiple objectives such as cost minimisation, product shortage and outdating. This complexity makes it difficult to include all relevant aspects while ensuring that the computation time required to optimise the blood product supply chain remains reasonable. Consequently, existing models typically fail to solve realistic-sized problems, thus have not found much use in supporting decisions faced by blood service practitioners. This research aims to develop a methodological framework for modelling platelet inventories, resulting in robust managerial recommendations. Specifically, we propose a two-stage stochastic programming model to define optimal target inventory levels that minimises costs, shortage and outdate in a decentralised decision-making setting. To keep the model tractable we exploit the problem structure to decompose it. Moreover, to ensure that the model is practically relevant, we develop it in close collaboration with practitioners from the Finnish Blood Service. The results of this optimisation model will enable practitioners to determine ordering policies that are less sensitive to demand forecast errors and assess the implications of extending the shelf life of platelets on inventory management in Finland.

3 - Identifying Changes in Demand for Perishable Products Using Statistical Process Control and Machine Learning Forecasting
Linden Smith, John Blake

Fast and accurate identification of demand shifts is crucial in the management of blood products. Canadian Blood Services (CBS) manages the collection and distribution of blood products in the Ottawa region of Ontario, Canada. CBS is planning a pilot project to apply pathogen reduction technology (PRT) to platelet production. The introduction of PRT is expected to shift hospital demand for platelets; however, the form of this shift is unknown. A lag time exists between the identification of a supply-demand imbalance and the ability to address it. The objective of this research is to determine how quickly and accurately demand shifts can be detected, to minimize lag time and thus provide better patient health outcomes. A discrete-event simulation was used to model platelet inventory and generate data for possible demand shift scenarios. Process control methods were used to detect and quantify shifts in demand. Forecasting methods were applied to the inventory data to reduce detection time. We found that statistical process control methods were effective in detecting demand shifts of all types and that forecasting decreased the time to detection. When the magnitude of the demand shift increased, the detection rate increased and the time to detection decreased. The consequences of a hidden demand shift are substantially less for shifts of smaller magnitude, mitigating the risk due to increased detection time. These results will be useful in minimizing the patient impact of PRT.

4 - Hybrid Simulation-based Optimization for Decision Support in Blood Supply-Chains
Dennis Horstkemper, Melanie Reuter-Oppermann, Michael Middelhoff, Adam Widera, Bernd Hellingrath

Blood supply chains are complex networks of independent actors comprising the collection, separation, testing and transfusion of blood products. A limited availability of blood donors and a mismatch of the available and required blood products combined with the complexity of the network make planning and controlling a blood supply chain difficult. These issues are further emphasized in times of crisis, like epidemics or natural hazards, which impose further challenges during the collection and distribution of blood products. We propose a simulation-based optimization environment to provide decision support for blood supply chains emphasizing crisis management. Unlike previous research, we hereby make use of a hybrid discrete event- and agent-based simulation to enable a better representation of the independent actors with their own planning processes and to model the emergent effects caused by a crisis. We evaluate the approach with a case-study of a South-African blood supply chain.

■ MG-39

Monday, 19:30-21:00 - Virtual Room 39

Data-driven approaches in planning, routing and scheduling problems

Stream: Routing, Logistics, Location and Freight Transportation
Invited session
Chair: *Nicklas Klein*

1 - Fuzzy C-Means and 2-Opt Algorithm for Food Distribution During Covid-19 Pandemic
Engin Bayturk, Şakir Esnaf, Tarık Küçükdeniz

Coronavirus (COVID-19) is a pandemic that effects millions of people all around the world nowadays. After the outbreak of COVID-19, many countries took preventive actions to reduce rate of spreading of the virus in all around the world. In many countries, education institutes changed their teaching to remote learning. Many companies started to work from home. In addition to that in most parts of the world lockdown actions are made by governments. However, in case of total lockdown decision that is applied strictly in special areas, people who work in service sectors such as: barbers, taxi drivers, café shop workers etc. couldn't work because of the restrictions. Some of those people couldn't gain money since they have no stable income due to their job sectors. Thus, some countries decided to help those people during pandemic and started to distribute food and vital items to survive. However, while people get their necessary items, long queues are appeared and that situation creates risks to increase the rate of virus spread. In this study, Fuzzy C-Means and 2-Opt algorithm is proposed for this problem. The proposed algorithm compared with genetic algorithm and two-phase Fuzzy C-Means and genetic algorithm in a real case study. Fuzzy C-Means and 2-Opt algorithm results are compared with benchmarking algorithms according to total travelled distance by all trucks.

2 - A Data-Driven Robust Approach for Planning the Charging Network for a Metropolitan Taxi Fleet
Gregor Godbersen, Rainer Kolisch, Maximilian Schiffer

We consider the problem of determining the cost-minimal private charging infrastructure for a ride-hailing fleet, taking vehicle operations and recharging decisions under uncertain customer demand into account. We propose a two-level optimization approach. At the first level, we select a subset of charging stations from a set of possible candidate stations. At the operational level, we solve a vehicle scheduling problem where we integrate visits to charging stations into vehicle operations. We solve the first level with a cutting plane approach and address the second level with column generation using resource-constrained shortest paths to generate vehicle schedules. We embed this deterministic approach into a data-driven adversarial sampling method using data from a taxi fleet of a metropolitan region to account for uncertain customer demand.

3 - A Deep Reinforcement Learning Algorithm for an Online Stochastic Profitable Tour Problem
Nicklas Klein

This work presents an end-to-end framework for solving online stochastic optimization problems based on deep reinforcement learning. In particular, we focus on an online stochastic version of the Profitable Tour Problem (PTP), which is a variant of the TSP with profits. The goal is to pick a subset of customers and maximize the sum of profits collected at these customers minus the total travel cost occurring during the tour. Profits are modeled through time-dependent random variables, whose realizations become available in an online matter. Most classical heuristic solution methods for combinatorial optimization problems require in-depth knowledge and expertise about the respective problem. In contrast to this, a deep reinforcement learning algorithm, called AlphaZero, has recently achieved state of the art performance in combinatorial games, such as chess or Go, solely through self-play. We adapt this methodology to apply it to problems of online stochastic optimization, in particular a version of the PTP. Specifically, a deep neural network provides a policy, which is then used in a Monte Carlo Tree Search (MCTS) to make fast decisions in the online stochastic environment. Training is performed on a set of scenarios on a per-instance basis. First computational studies show promising results, improving the solution quality significantly through training and outperforming iterative integer programming methods.

4 - Improving vehicle routing by learning demand uncertainties from historic data: a case study
Silia Mertens, Ahmed K.A Abdullah, Yves Molenbruch, Kris Braekers, An Caris, Tias Guns

VRPs have already been widely studied in literature, but the inclusion of uncertainty aspects is still less studied. Stochastic problems assume that only a probability distribution is known on the uncertain parameters. This study focuses on the VRP with time windows and stochastic demands, based on a real-life problem faced by a 3PL. Specified quantities often deviate between the actual quantities when arriving at the customer, which makes it difficult to make a reliable planning. Stochastic demands can lead to inefficient use of vehicle capacity or to capacity shortages, leading to costly corrective actions when executing planned collection routes. A two-stage stochastic programming with recourse method is applied to model the problem, with the aim to minimize total expected costs. At a route failure, a detour to depot recourse policy is used. When a failure occurs, the vehicle returns to the depot to unload. Afterwards, it resumes its route as planned. This study extends the state of the art by including the effect of expected violations of time windows, maximum route duration and other time-related constraints into the recourse cost function. An iterated local search algorithm is proposed to solve the problem. Different learning techniques are compared to estimate the probabilities of failure at every customer in a route from real-life historic data. Experimental results demonstrate that in general, total costs can be reduced when making use of the two-stage approach.

■ MG-40

Monday, 19:30-21:00 - Virtual Room 40

Optimisation algorithms for various deterministic and stochastic scheduling problems

Stream: Scheduling and Project Management
Invited session
Chair: *Mario Vanhoucke*
Chair: *Tom Servranckx*

1 - The impact of the optimisation criterion in multi-project scheduling: a benchmark of metaheuristic solution procedures
Dries Bredael, Mario Vanhoucke

A wide variety of metaheuristic solution strategies have been described in literature to solve the Resource-Constrained Multi-Project Scheduling Problem (RCMPSP). The purpose of this study is to benchmark these metaheuristics on a novel, state-of-the-art dataset with the goal of improving comparability between these studies. These solution methods all have distinct goals or optimisation criteria and only seldomly analyse their performance on other metrics. This is a common characteristic originating from the problem definition of the RCMPSP itself that sets multi-project scheduling apart from (single-)project scheduling and requires tailored-to solution strategies. Multi-project scheduling problems generally define an optimisation criterion as a combination of measurements on multiple points in the project network e.g., the average project delay. In contrast, single project scheduling problems limit themselves to optimising a single point objective, usually the maximum activity completion time. To allow for a fair comparison between strategies, all methods are benchmarked for a variety of optimisation criteria. This is followed by an investigation into the effect of the objective function on other metrics separate from the effectiveness of the procedure. A trade-off between solution metrics and interaction effects with building blocks of solution procedures can be observed.

2 - Generalized Multi-Scale Stochastic Reservoir Opportunity Index for Enhanced Well Placement Optimization Under Uncertainty in Green and Brown Fields
Forough Vaseghi, Mario Vanhoucke, Mohammad Ahmadi, Mohammad Sharifi

Well placement planning is one of the most challenging issues in any field development plan. In this study, we have used Reservoir Opportunity Index (ROI), as a spatial measure of productivity potential for green fields, which hybridizes the reservoir static properties, and have defined Dynamic Measure (DM) for brownfields, which also takes into account the current dynamic properties. The purpose of using these criteria is to diminish the search region of optimization algorithms and as a consequence, reduce the computational time and cost of optimization, which are the main challenges in well placement optimization problems. However, considering the significant subsurface uncertainty, a probabilistic definition of ROI (SROI) or DM (SDM) is needed, since there exist an infinite number of possible distribution maps of static and/or dynamic properties. To build SROI or SDM maps, the k-means clustering technique is used to extract a limited number of characteristic realizations that can reasonably span the uncertainties. Moreover, to determine the optimum number of clustered realizations, Higher-Order Singular Value Decomposition method (HOSVD) is applied which can also compress the data for large models in a lower-dimensional space. Additionally, the multiscale spatial density of ROI or DM is introduced, which can distinguish between regions of high SROI (or SDM) in arbitrary neighborhood windows from the local SROI (or SDM) maxima with low values in the vicinity.

3 - Order Acceptance and Capacity Planning in a Dynamic and Stochastic Environment
Rojin Nekoueian, Mario Vanhoucke, Amin Dehghanian, Mohsen Akbarpour shirazi

Order acceptance in a dynamic and stochastic multi-project environment is the process of accepting dynamically arrived orders in stochastic intervals to enter a system as a project. We investigate an optimal policy for joint order acceptance and capacity planning decisions, which are made by different departments in a company. One may want to boost the revenue by accepting more projects, while resources are constrained and subject to breakdown, and an increase in the number of system projects will lead to congestion in the system. Consequently, the due date of projects will not be met, and penalties will be incurred. Moreover, such decisions on the tactical level make scheduling on the operational level more convenient. The system has a limited capacity and includes several known types of projects, stochastic resource breakdowns, and repair duration. To crash the stochastic duration of projects, a decision on the usage of non-regular capacity should be made. This problem is modeled as a continuous-time Markov decision process to maximize the profit. To find an optimal policy, we uniformize the proposed model to employ value iteration. Our numerical results show that the project's income has a great effect on project acceptance rather than project duration. Also, by using non-regular capacity, the number of accepted projects of any type will increase, and optimal decision on its usage depends on the number of waiting projects in the system.

4 - An evaluation of the causal risk modelling approaches for forecasting project cost and duration
Izel Unsal Altuncan, Mario Vanhoucke

Due to the advances in the use of causal maps in decision making, causality between project risks have started to receive attention. So-called risk models that incorporate causal interactions among risks now serve as tools for better risk assessment, for decision support and for more accurate cost and duration forecast. Until recently, majority of the research efforts have focused on the use of risk models for analyzing risk sensitivity and for evaluating potential risk response actions. On the other hand, the research effort devoted to forecasting the project performance has been in limited amount. This research gives an overall overview of the existing literature on the use of risk models and further focuses on the use for cost and duration forecasting. To the best of our knowledge, two causal modelling methodologies namely Structural Equation Modelling (SEM) and Bayesian Networks(BN), have been adapted for that purpose. This paper compares the SEM and BN approaches and evaluate their forecasting performance on a wide variety of artificial project data. The contribution of this research is 3-fold. First, we propose a classification scheme for the concepts used in risk models to bring clarity in the confusing terminology in literature.Next, we illustrate the use of each forecasting approach on two risk models, both of which are validated on the same empirical dataset. Finally, we compare the forecasting performances of the two approaches using unseen artificial project data.

■ MG-41

Monday, 19:30-21:00 - Virtual Room 41

Aspects of passenger routing in public transport

Stream: Timetabling and public transport
Invited session
Chair: *Philine Schiewe*

1 - The Price of Symmetry in Line Planning
Berenike Masing, Niels Lindner, Ralf Borndörfer

One of the fundamental steps in the optimization of public transport is line planning. It involves determining lines and assigning frequencies of service such that costs are minimized while also maximizing passenger comfort and satisfying travel demands. We formulate the problem as a mixed integer linear program that considers all circuit-like lines in a graph and allows free passenger routing. Traveler and operator costs are included in a linear scalarization in the objective. We apply said programming problem to the "Parametric City", a generic, flexible city model developed by Fielbaum et al. The corresponding graph and demand are controlled by some parameter choice and are both rotation symmetric. It stands to reason to assume that the symmetry is reflected in the optimal line plans and passenger routes. This, however, is not necessarily true: For some instances of the Parametric City optimal solutions are asymmetric.

Using group theory, we show that either a symmetric line plan, or a symmetric passenger flow is sufficient for the existence of the other. Further, we introduce the "symmetry gap" to measure the deviation of a symmetric to its optimal solution. As computational results suggest a small gap, we examine it by theoretical means: Bounds on the gap enable us to derive for which instances of the Parametric City the symmetry assumption is justified, when it provides us with a suitable approximation, and in which cases this assumption is detrimental.

2 - Passenger demand estimation during line plan optimization
Johann Hartleb, Marie Schmidt, Dennis Huisman, Markus Friedrich

We present a mixed integer linear program (MILP) for line planning with integrated mode and route choice. In contrast to existing approaches, the mode and route decisions are modeled according to the passengers' preferences and exact solution approaches can be applied to solve the MILP. The model aims at finding profit-optimal line plans while estimating the corresponding passenger demand with choice models. This yields line plans that are cost efficient for operators and at the same time attractive to passengers. By suitable preprocessing of the passengers' utilities, we are able to apply an arbitrary choice model for mode choices using linear constraints. We provide means to improve the solution performance and test them computationally. In experiments on the Intercity network of Randstad, a metropolitan area in the Netherlands, we show the superiority of our model compared to a standard line planning model with fixed passenger demand. Furthermore, we demonstrate with the help of our model the limitations and possibilities for operators when reacting on changes in demand in an optimal way. The results suggest that operators should regularly update their line plan in response to changes in travel demand and estimate their passenger demand during optimization.

3 - Optimizing adaption and travel times in timetabling using time slices
Philine Schiewe

When optimizing timetables from a passengers' perspective, the most common objective is to minimize travel time. Often, a penalty for transfers is also included. However, the frequency of service cannot be measured by looking at the travel time alone. Including the adaption time, i.e., the time between the desired start of a passenger's journey and its actual start, therefore is an important component to measuring the service quality of a timetable.

Instead of assuming that passengers arrive uniformly distributed at the start of their journey, we assume that the desired departure time of each passenger is known. To reduce the number of routes that have to be computed and to represent flexibility of the passengers, we aggregate departure times into time slices. The adaption time is only counted when the start of the journey is outside the desired time slice. We use this definition of adaption times using time slices in an integrated model for periodic timetabling and passenger routing. We investigate the choice of the time slices as well as the structure of the underlying line plan on the service quality for the passengers. Our models are tested on different data sets of the open source software framework LinTim.

4 - Operational optimization of integrated mobility systems with dynamic and stochastic characteristics: modeling and first results.
Soukaina Bayri, Yves Molenbruch

Integrated mobility systems are gaining popularity in many Western countries. These systems allow passengers to travel by a combination of public and demand-responsive transport services. Based on a set of user requests and corresponding service requirements (e.g., time windows, maximum trip time, ...), the routes and schedules of the demand-responsive services are planned by a mobility provider. They must be aligned to the public transport timetables to allow efficient transfers. However, the academic literature lacks insights in (1) how the operational planning of an integrated mobility system should be designed and (2) how this planning can dynamically be revised in case of unexpected events, such as delays on the PT network causing missed transfers. In addition, the literature also lacks insights in how failures caused by these dynamic events can be anticipated in the initial planning, with the aim of incorporating robustness into the planning and increasing the reliability of the solutions.

Therefore, the main goal of this research is to develop a quick and efficient planning algorithm for integrated mobility systems that responds to all the aforementioned aspects and which will eventually enable real-life systems to operate in the most efficient and user-oriented way. In this talk, a mathematical model (MILP) describing the concerning problem will be presented as well as the first results from experiments with this model.

■ MG-42

Monday, 19:30-21:00 - Virtual Room 42

Modern trends in MDPs

Stream: Stochastic Dynamic Programming
Invited session
Chair: *Sandjai Bhulai*

1 - Data-Driven Consumer Debt Collection via Machine Learning and Approximate Dynamic Programming
Sandjai Bhulai, Ruben van de Geer, Qingchen Wang

In this talk, we develop and test a framework for the data-driven scheduling of outbound calls made by debt collectors. These phone calls are used to persuade debtors to settle their debt, or to negotiate payment arrangements in case debtors are willing, but unable to repay. We determine on a daily basis which debtors should be called to maximize the amount of delinquent debt recovered in the long term, under the constraint that only a limited number of phone calls can be made each day. Our approach is to formulate a Markov decision process and, given its intractability, approximate the value function based on historical data through the use of state-of-the-art machine learning techniques. Specifically, we predict the likelihood with which a debtor in a particular state is going to settle its debt and use this as a proxy for the value function. Based on this value function approximation, we compute for each debtor the marginal value of making a call. This leads to a particularly straightforward optimization procedure, namely, we prioritize the debtors that have the highest marginal value per phone call. Our policy collects more debt in less time, whilst using substantially fewer resources — leading to a large increase in the amount of debt collected per phone call.

2 - Bayesian Adaptive Mastery Assessment in Online Tests via Machine Learning
Anni Sapountzi, Sandjai Bhulai

We propose a new model to assess the mastery level of students in online tests. The model, called Bayesian Adaptive Mastery Assessment (BAMA), uses information on the accuracy and the response time of the answers given and infers the mastery at every step of the assessment. The BAMA model is formulated as a partially-observed Markov decision process (POMDP). The value function in the POMDP is difficult to calculate. Therefore, we apply a combination of Monte Carlo simulation and machine learning to approximate the value function. Afterward, the optimization becomes numerically tractable. The optimal policy balances the length of the assessment and the certainty of the mastery inference.

3 - Dynamic Inventory Control with Fixed Setup Costs and Unknown Discrete Demand Distribution
Mehdi Davoodi, Michael Katehakis, Jian Yang

We study a dynamic inventory control problem involving fixed setup costs and random demand distributions. With an infinite planning horizon, model primitives including costs and distributions are set to be stationary. Under a given demand distribution, an (s,S) policy has been known to minimize the long-run per-period average cost. Out of the need to model situations involving new products or unencountered economic conditions, however, we depart from the traditional model by allowing the stationary demand distribution to be largely unknown, to the effect that it could be anywhere in a given ambiguity set. Our goal is to rein in the long-run growth of the regret resulting from applying a policy that strives to learn the underlying demand while simultaneously meting out ordering decisions based on its learning. We propose a policy that controls the pace at which a traditional (s,S)-computing algorithm is applied to the empirical distribution of the demand learned over time. The regret incurred from the policy is shown to grow over time at an O(T1/2ln T1/2)-sized rate. Other insights are gained from a simulation study.

4 - Investigation of MDP Models for Sequential Procurement Auctions
Kartikeya Puranam, Michael Katehakis

We model the problem of a firm that in order to fill the demand of its market builds inventory by participating in sequential auctions, where different participating bidders different private valuations for the product. We provide further insight into the structure of the optimal procurement strategy by endogenizing the probability of winning an auction. We illustrate the results with computational studies.

■ MG-43

Monday, 19:30-21:00 - Virtual Room 43

City Logistics

Stream: Environmental Sustainability in Supply Chains
Invited session
Chair: *Tina Wakolbinger*

1 - Implementation of cargo bikes in urban freight delivery schemes - benefits and challenges
Alexandra Anderluh

Cargo bikes are an increasingly familiar sight in urban areas. They are especially used in the private sector - to bring large purchases home or to transport children. Cargo bikes are enjoying growing popularity, as they can contribute to the livability in cities because of their flexibility and maneuverability in traffic and, above all, they are emission-free in use. In urban freight transport cargo bikes are also raising interest, (1) to reduce traffic-related emissions and (2) to be less affected by traffic jams and problems with finding a parking spaces. Cargo bikes for delivering parcels are already in use by parcel service providers in numerous cities like Vienna, Hamburg or London. They are above all used in the city center or in specific urban areas, which contributes to reduce the number of delivery vans for parcel delivery in these areas. The adaption of logistics processes to cargo bike usage also comes along with some challenges, such as the selection of a suitable cargo bike type, the suitability of the products and the appropriate delivery radius. Additional measures like adapted routing algorithms or the implementation of micro depots within an urban area, which can be used as intermediate storage facility but also to consolidate deliveries, need to be considered. Therefore, benefits and challenges of cargo have to be thoroughly evaluated when planning to implement these emission-free and flexible vehicles in urban logistics processes.

2 - Collaborative Model for Inventory Routing in City Logistics

Titi Iswari, Kris Braekers, An Caris

The Inventory Routing Problem (IRP) provides integrated logistics solutions by optimizing inventory management and vehicle routing decisions simultaneously. Currently, only a few studies consider the integration of inventory and routing decisions along with collaboration aspects in a city logistics context. Therefore, we investigate the impact of integrated inventory routing decisions and collaborative mechanisms in a city logistics context. We consider three scenarios with increasing level of collaboration. For each scenario, a mathematical model is presented, together with first experimental results. The first scenario is a basic IRP model with multiple suppliers. In this scenario, each customer defines its replenishment policy and each supplier determines its optimal delivery plan independently. In the second scenario, customers determine their amount of orders and suppliers send their products to the customers via a city-hub. The city-hub determines the optimal delivery routes for the customers with a heterogeneous vehicle fleet making multiple trips. In the third scenario, the city-hub receives the products from the suppliers, defines the optimal delivery routes and decides on the quantity delivered to each customer at each period.

3 - Evaluating a two-echelon distribution network: A case study in city of Innsbruck

Belma Turan, Vera Hemmelmayr

In order to make urban freight transportation more sustainable, a shift towards environmentally friendly freight vehicles becomes inevitable. Many European cities have been actively promoting the usage of cargo bikes in urban freight transport, especially as a smart solution to the crucial last mile problem. Cargo bikes have fewer access restrictions and need less space than classical vans and therefore can reduce congestion in urban areas. In this work, we analyze the benefits of using the cargo bikes for the last mile delivery in the city of Innsbruck. We propose a two-echelon distribution network with logistic hubs located at the outskirts of the city center. Delivery vans are used for deliveries from the city distribution center (warehouse) to the logistic hub and cargo bikes are used for delivery from the hub to the end customers. We analyze the impact of two-echelon model on both economic and ecological level and compare the new solutions with the single-echelon one. Computational experiments based on realistic instances are reported.

■ MG-44

Monday, 19:30-21:00 - Virtual Room 44

Speed networking

Stream: Practice of OR (Making an Impact)
Invited session
Chair: *Ruth Kaufman*

1 - Speed networking: converting names into colleagues

Ruth Kaufman

Meet your peers in a friendly, safe and fun way - see how serendipity can expand your horizons.

A conference is not just about listening to people present papers; it is about meeting people and having conversations. And not just meeting up with old friends, or having planned conversations about topics, but bumping into people you didn't know existed, and having conversations about cross-overs and ideas that you didn't know were possible. This is where much of the learning, inspiration and lasting personal connections happen.

This sort of meeting and conversation can be difficult at the best of times, especially for people who are shy (that's many of us), or who feel that everyone else knows things that they don't (that's most of us), or who are new to EURO or OR. It is even harder when the conference is virtual, and you cannot speak to the person next to you in the auditorium or behind you in the coffee queue. The purpose of this session is to make networking easy, enjoyable, and fruitful.

This session will start with an introduction to 'networking' and how to stop worrying and make the most of the chance to meet friendly and like-minded peers. Then the talking starts: you will be randomly paired or grouped with one or two other people, with no more than a couple of minutes each to introduce yourself and your work area/interests, and exchange contact details so that you can follow up at your leisure, if you choose. When everyone in the group or pair has had a chance to speak, we will reshuffle so that you are grouped up with someone different. After several rounds (depending on how many people come along) we will return to plenary for a review and more information about the EURO Working group on OR in Practice (the 'practitioner network').

For the latest on the 'Making an Impact' programme, and for any last-minute changes to arrangements, please see https://euro2021athens.com/specific-sessions/

■ MG-45

Monday, 19:30-21:00 - Virtual Room 45

Emerging optimization problems in air mobility

Stream: Specific Applications of OR (contributed)
Contributed session
Chair: *Mercedes Pelegrín*
Chair: *Renan Spencer Trindade*

1 - Analytical solution for 2D aircraft conflict resolution problem

Fernando Hugo Dias, Hassan Hijazi, David Rey

Efficient solution methods for the aircraft conflict resolution problem is a fundamental stepstone towards automation in air traffic management. One of the main hurdles to achieve a higher level of performance of automated air traffic control systems is the presence of trigonometric and nonlinear expressions in aircraft conflict resolution formulations. This is particularly challenging for mathematical programming approaches which aim to find global optimal solutions for aircraft deconfliction problems. In this paper, we address the two-dimensional aircraft conflict resolution problem and focus on deriving analytical solutions for the two-aircraft conflicts. We propose a decomposition of the initial nonconvex formulation based on a disjunction and which provides a pair of convex optimization problems under reasonable assumptions. We then use Karush-Kuhn-Tucher conditions to identify analytical expressions for optimal aircraft velocity manoeuvres that guarantee separation. Numerical tests using different two-aircraft instances are provided to illustrate the approach. We also discuss how the proposed analytical solution for two-aircraft conflicts may be used to develop scalable solution methods for multi-aircraft conflict resolution problems.

2 - Optimal Location of Safety Landing Sites
Liding Xu, Claudia D'Ambrosio, Leo Liberti, Sonia Vanier

Vertical Take-Off and Landing (VTOLs) vehicles are used to move passengers between vertiports in urban air mobility. Safety landing sites (SLSs) cover the trajectory of VTOLs for emergency landings. We study the optimal placement of SLSs in the air transportation network under budget on SLS installation. We propose two models based on the k-splittable and the un-splittable multi-commodity flow problems. We develop edge and path formulations for the problem. Edge formulation is solved by a branch-and-bound algorithm. We propose a branch-and-price approach to solve the path formulation. We perform numerical experiments on a set of automatically generated instances.

3 - Integrated Optimization of Free-Flight Trajectories and Runway Scheduling
Benno Hoch, Frauke Liers

In the surroundings of airports, both the planning of conflict-free trajectories as well as determination of runway schedules are crucial and challenging tasks. In current practice, the resulting continuous and discrete optimization problems are often solved sequentially, leading to potential losses, e.g. in runway utilization or carbon emission. Those losses are further worsened by the implementation of strict, predefined arrival routes. In this work the goal is to overcome those drawbacks. Therefore, we develop an integrated optimization model for conflict-free multi-aircraft trajectory planning and runway scheduling in a free flight environment. We use a space-time discretization and model conflict-free trajectories by an integer program. For the given discretization this is designed to provide optimal, piecewise-linear reference trajectories and a runway scheduling for multiple aircraft. Thereby, even for moderately sized instances, a sufficiently detailed representation of 3D- airspace and time leads to huge models, which cannot be treated by current hard- and software. To overcome this, we develop an iterative adaptive-refinement algorithm: Starting from an optimal solution in a coarse discretization the algorithm re-optimizes trajectories in a neighborhood of the current solution with a higher resolution. Computational results illustrate improvements made by the approach.

4 - Sequential convex MINLP technique for aircraft conflict avoidance problem
Renan Spencer Trindade, Claudia D'Ambrosio, Antonio Frangioni, Claudio Gentile

Our work studies the aircraft conflict avoidance problem in two-dimensional space. It is a real-life problem inspired by Air Traffic Management (ATM), which ensures safe operation in the sky. The problem is defined given a set of aircraft observed by the ATM. All share the same airspace and flight level within a time window. Each aircraft has a planned trajectory containing three values: (1) initial coordinates (2) heading angle, indicating flight direction (3) velocity, which is constant in our problem. All trajectories must respect the minimum safety distance between the aircraft during the whole trip. In our problem, aircraft can adjust trajectory using only one maneuver, which changes the heading angle. The aim is to find the minimum heading angle variation for all trajectories, respecting safety constraints. We propose a formulation in which all the constraints appear as the sum of univariate functions. Then, we apply the Sequential Convex Mixed Integer Non-Linear Programming to the non-linear constraints. The technique deals with convex or concave intervals separately. We preserve the convex intervals as they are, while the concave intervals are linearized. Hence, a convex relaxation of the original problem with valid lower bounds is defined. The algorithm iteratively solves the model and adds more breakpoints to improve the lower bound. We obtain feasible solutions to the problem using a local search by fixing binary variables in the original problem.

■ MG-48

Monday, 19:30-21:00 - Virtual Room 48

Michael Carter

Stream: Keynotes
Keynote session
Chair: *Joana Matos Dias*

1 - How Can We Make a Real Difference in Healthcare? The Challenges of Implementation
Michael Carter

Most of us who work in OR applications in healthcare are frustrated by the fact that planners, managers and decision makers do not seem to be suitably impressed with the mathematical beauty of our models. The literature abounds with hundreds of application papers; but when we take a closer look, few of them describe implementation. The problems in the healthcare industry are generally very similar to corresponding problems in any other sector. Hospitals have staffing issues, budget constraints, purchasing decisions, scheduling, planning, etc. The differences are subtle and often related to the culture. Over the years, I have encountered many challenges and I have been able to design approaches to deal with many of them. A few years ago, I was asked to pick the five top challenges. I can easily rattle off thirty, but selecting five was itself a challenge. In this talk, I will outline my perception of the major hurdles, provide a few examples and discuss strategies for overcoming them.

Tuesday, 9:00-10:00

■ TA-21

Tuesday, 9:00-10:00 - Virtual Room 21

Janny M.Y. Leung [IFORS Distinguished Lecture]

Stream: Plenaries
Plenary session
Chair: *John Psarras*

1 - Public Transportation for Smart Cities
Janny Leung

The idea of a smart city is one that utilizes IoT technologies and data analytics to optimize the efficiency of city operations and services, so as to provide a high quality of life for its citizens. Due to reduced public funding, many public transportation systems are already facing challenges to maintain their services. For a smart city, the goal of public transportation is not simply the movement of people, but to provide mobility for living. This will be particularly challenging due changes in habitation trends and work patterns. For example, the growth of mega-cities have led to extreme traffic congestion in city centres and urban sprawl on their outskirts. In order to provide sufficient coverage/frequency, an integrated co-ordinated multi-modal public transportation system is needed, leading to substantial increase in operational complexity. Environmental concerns and the recent pandemic may also have changed work and commuting patterns in the future, with more people working from home and companies adopting flexible work shifts. For smart cities, public transportation must offer ubiquitous access, real-time response to demand, convenience and quality service, and energy-efficient operations. This talk will discuss the challenges in network design, operations planning, scheduling and management of smart public transportation systems. Some case studies will also be presented.

Tuesday, 10:30-12:00

■ TB-01

Tuesday, 10:30-12:00 - Bulding A, Amphitheatre

Katia Sycara

Stream: Keynotes
Keynote session
Chair: *Milosz Kadzinski*

1 - The Science of the Deal: Teaming and Negotiating in Artificial and Human Societies
Katia Sycara

Operations Research has focused on modeling processes and interactions in human society so as to be able to characterize these processes, analyze and understand their nature and predict their possible effects. Recently and increasingly artificial agents enter human societies as decision support systems, as computational processes on the Web or as embodied presence in the form of robotic service providers or assistants. This engenders the need to develop algorithms that allow those artificial agents to autonomously interact in various ways, such as negotiating, forming coalitions, or making decisions as a team. In this talk we present some of our work in modeling these interactions, giving examples that include models of human decision making and also models of artificial agents that can also be used in interactions of the agents with humans in human-autonomy teaming scenarios. Applications include crisis response, search and rescue and environment exploration. We present insights and also discuss potential vulnerabilities of consensus protocols.

■ TB-02

Tuesday, 10:30-12:00 - Bulding A, Room A5

Dynamical Systems and Mathematical Modeling in OR 1

Stream: Dynamical Systems and Mathematical Modeling in OR
Invited session
Chair: *Gerhard-Wilhelm Weber*
Chair: *Panagiotis Andrianesis*

1 - Alternative methods of quantitative analysis of a pandemic COVID - 19 in the Czech Republic
Jakub Hanousek

This study analyses a variation in spread of disease COVID - 19 in a region of the Czech Republic. The Czech Republic has 77 regions, and it is a one of the most affected country by disease COVID - 19 in the word. The data cover a period since March 2020 to March 2021 and come from Institute of Health Information and Statistics of the Czech Republic. The goals of this study are to arrange the regions in the Czech Republic against the fight of disease COVID - 19 and show the variation between regions in the Czech Republic.

This study works with advanced data envelopment analysis models especially dual models with uncontrollable outputs. Data envelopment analysis is a method based on a linear programming that measure efficiency of units. The advantage of this method is an optimalization weight of each criteria to maximize a score from each unit.

We have many data sets about spread Covid - 19 in the Czech Republic. We can compile many criteria from this data sets. The question is how to organize criteria objectively. There is huge variation between regions of the Czech Republic in spread of COVID - 19. The

Government of the Czech Republic applied national lockdown to stop the disease. The regional lockdown probably would be preferable and more effectiveness in this situation.

2 - Optimal Grid-Distributed Energy Resource Coordination
Panagiotis Andrianesis, Na (Lina) Li, Michael C. Caramanis

We consider the day-ahead operational planning problem of a radial distribution network hosting Distributed Energy Resources (DERs) including rooftop solar and storage-like loads, such as electric vehicles. We present a novel hierarchical decomposition approach that is based on a centralized AC Optimal Power Flow (AC OPF) master problem interacting iteratively with self-dispatching DER sub-problems adapting to real and reactive power Distribution Locational Marginal Costs. We illustrate the applicability and tractability of the proposed approach on an actual distribution feeder, while modeling the full complexity of spatiotemporal DER capabilities and preferences, and accounting for instances of non-exact AC OPF convex relaxations. We show that the proposed approach achieves optimal Grid-DER coordination, by successively improving feasible AC OPF solutions, and discovers spatiotemporally varying marginal costs in distribution networks that are key to optimal DER scheduling by modeling losses, ampacity and voltage congestion, and, most importantly, dynamic asset degradation.

3 - Hybridization of Sensors Through Neural Networks for Rockets Guidance Applications
Raúl de Celis, Luis Cadarso

The guidance, navigation and control (GNC), of aircraft and space vehicles, and more concretely artillery rockets, has been one of the spearheads of research in the aerospace field in recent times. Improving accuracy is cornerstone for ballistic projectiles. Using inertial navigation systems and Global Navigation Satellite Systems (GNSS), accuracy becomes independent of range. However, during the terminal phase of flight, when movement is governed by non-linear and highly changing forces and moments, guidance strategies based on these systems provoke enormous errors in attitude and position determination. Employing additional sensors, which are independent of cumulative errors and jamming, such as the quadrant photo-detector semi-active laser, can mitigate these effects. The development and training of neural networks with applications in guidance, navigation and control of aerospace vehicles seems to be currently very popular for this purpose. This research presents a new nonlinear hybridization algorithm to feed navigation and control systems, which is based on neural networks. The use of a neural network for the estimation of parameters based on the dynamics of the projectile presents the advantage that once this network is trained, it is no longer necessary to know the physical-mathematical foundations that govern the dynamics of the vehicle, but it is the network that, based on input data, returns dynamic parameters that can later be used within the GNC algorithm.

■ TB-03

Tuesday, 10:30-12:00 - Bulding A, Room 3A

Lot sizing: decomposition approaches and applications

Stream: Lot Sizing, Lot Scheduling and Production Planning
Invited session
Chair: *Wilco van den Heuvel*
Chair: *Stéphane Dauzere-Peres*

1 - Parallelized decomposition approaches to solve the Capacitated Lot-Sizing Problem with Setup Times and Ending Inventories
Mehdi Charles, Stéphane Dauzere-Peres, Safia Kedad-Sidhoum

To model production processes in many industrial contexts, the well-known Capacitated Lot-Sizing Problem with setup times and lost sales has been modified by adding a target ending inventory for all items and a maximum ending inventory per item. To solve this problem, two approaches are proposed that can be accelerated using parallelization. The first approach uses a parallelized version of the Relax-and-Fix algorithm, where time intervals are not fixed chronologically but, at each iteration, different time intervals are fixed in parallel. The best interval is then picked according to a selection strategy. The approach is tested using both an aggregate formulation and a disaggregate formulation. Reconstruction methods are also proposed. The second approach is a Lagrangian heuristic where capacity constraints are relaxed. The Lagrangian relaxed problem is polynomial when the maximum ending inventory is identical for all items. It can be reduced to the resolution of a polynomial number of uncapacitated lot-sizing problems with ending inventory, which can be solved independently using dynamic programming. To reduce lost sales, a reconstruction algorithm is introduced that consists of successive smoothing passes in which production quantities are moved to later/earlier periods. Also, units of ending inventories are moved from one product to another product. Computational results will be reported to assess the efficiency of both approaches.

2 - A comparative analysis of different approaches for production lot sizing and scheduling in the animal feed premix industry
Nebojsa Bojovic, Susana Val, Milos Milenkovic, Dejan Lutovac

The global feed premix market size is projected to grow at a compound annual growth rate of 6.2% from 2019. to reach a value of USD 30.9 billion by 202. The growth of the market is a consequence of increased consumption of livestock-based products. Increased demand coupled with higher consumer expectations in terms of production quality puts a high pressure on producers to increase the efficiency of their production process. Production process of animal feed premixes can be modelled as a MIP problem that incorporates decisions of lot sizing, scheduling and assignment of operators subject to a set of real operating constraints. Two solution strategies, namely MIP-based heuristics and Benders decomposition approach are developed and their performances compared with monolithic solution.

3 - A Benders decomposition approach to the lot-sizing and market selection problem
Wilco van den Heuvel, Semra Agrali, Z. Caner Taşkın

In the NP-hard lot-sizing and market selection problem one needs to select the markets to serve and construct a production plan to satisfy the demands of the markets selected. We consider single and multi-objective version of the problem with trade-offs between revenues and costs, as well as market share and costs. We show how to apply a Benders decomposition approach in an effective way by utilizing an efficient procedure to get the dual variables of the Benders subproblems. Moreover, we establish a relationship between the Benders cuts and the core of a corresponding cooperative lot-sizing game, where in the latter game the lot-sizing costs need to be shared among players in a fair way. Finally, we show how to reuse the Benders cuts to get an effective algorithm for the multi-objective version of the problem.

■ TB-05

Tuesday, 10:30-12:00 - Building Δ, Room Δ105

OR in Aviation 1

Stream: OR in Aviation
Invited session
Chair: *Alexandre Jacquillat*
Chair: *Mattia Cattaneo*

1 - **A Novel Approach to the Tail Assignment Problem at Vueling Airlines**
Luis Cadarso, Manuel Fuentes González, Vikrant Vaze, Cynthia Barnhart

Airline planning is a field rich in combinatorial optimization problems. Flights and airports make up the network where aircraft and passengers fly. In order to schedule aircraft, assignments of fleet types to flights and of aircraft to routes must be determined. The former is known as the fleet assignment problem while the later is known as the aircraft routing problem in the literature. Aircraft routing is usually addressed as a feasibility problem whose solution is needed for constructing crew schedules. All these problems are usually solved from 4 to 6 months before the day of operations. Therefore, there is limited information regarding each aircraft's operational condition. The tail assignment problem, which has received limited attention in air transportation literature, is solved when additional information regarding operational conditions is revealed aiming at determining each aircraft's route for the day of operations accounting for the originally planned aircraft routes and crew schedules. Therefore, it is a problem to be solved the day before operations. We propose a mathematical programming approach based on sequencing that captures all operational constraints and maintenance requisites while operational costs are minimized and schedule changes with respect to original plans are minimized. Computational experiments are based on realistic cases drawn from a Spanish airline, which features a network with more than 1000 flights and more than 100 aircraft.

2 - **A Comprehensive Approach to Airline Operations Recovery at Vueling Airlines**
Manuel Fuentes González, Luis Cadarso, Vikrant Vaze

During daily operations of an airline network, various incidents may cause deviations from the planned operations, sometimes making it impossible to operate the schedule as originally planned. In such situations airlines need to adjust the schedule for the time period of the incident, and then carry out further recovery steps in order to get back to the original schedule. When a disruption occurs, schedules, and aircraft assignments and routings are modified such that the passenger demand can be matched, while complying with a myriad of constraints regarding operative and maintenance requirements. Curfews, soft and hard constraints are examples of operative constraints. On the side of maintenance requirements, all the airline specific constraints are included. In addition, crews are rescheduled to comply with the government regulations and collective bargaining labor agreements. Finally, the European flight delay compensation regulation (EC) No 261/2004 , which establishes common rules on compensation to passengers in the event of disruptions, is also considered. We propose a mathematical programming approach which minimizes operational costs, delays and schedule changes with respect to original plans, emphasizing an on time performance of 15 minutes. Computational experiments are based on realistic cases drawn from a Spanish airline, which features a network with more than 1000 flights and more than 100 aircraft.

■ TB-06

Tuesday, 10:30-12:00 - Building Δ, Room Δ103

Insurance risk management

Stream: Actuarial modeling and risk management
Invited session
Chair: *Valeria D Amato*

1 - **Weather Index Insurance by satellite data: the basis risk measurement**
Valeria D Amato, Maria Carannante

Weather index insurance is a recent innovation insurance to protect against the economic consequences of adverse meterological events. In agricolture, by using an "index" of weather observations as a proxy for crop loss, the problems of traditional indemnity insurance are reduced or eliminated. Weather index insurance removes the subjective nature of insurance adjustment as well as the problems of adverse selection and moral hazard that are present in the traditional indemnity insurance model (Norton et al. 2013). Nevertheless The discrepancy between experienced losses and actual indemnification, basis risk, is a key challenge. In this research we deepen this critical aspect, by measuring the different components (Dalhaus et al. 2018) through the implementation of satellite data.

2 - **Insurance Portfolio Strategies with Time Varying Multiples Based on Good and Bad Volatility Dynamics**
Hachmi Ben Ameur, Zied Ftiti, Wael Louhichi, Jean-Luc Prigent

We propose an extension of one of the main portfolio insurance strategies, namely the Constant Proportion Portfolio Insurance (CPPI) strategy. In our model, the conditional multiple is determined using key factors governing the return process, namely the good (upside market) and bad (downside market) volatilities. For the CPPI method, the predictability of volatility is crucial for the choice of rebalancing strategies. For example, the predictability of bad volatility helps to better manage the gap risk while taking account of good volatility improves the portfolio performance. Our empirical analysis is mainly conducted on S&P 500 index as risky asset. We also perform a back test of the strategies, using a sliding window method to dynamically estimate model parameters based on the last two years of daily returns. The proposed models lead to signi. . . cantly better out-ofsample performances. Our results underline the very signi. . . cant interests of introducing time varying multiples based on good and bad volatilities, from both the theoretical and operational points of view. Keywords: Portfolio insurance; CPPI; Good and bad volatilities. JEL classification: G11; C58; D53

3 - **An Efficiency Comparison of the Life Insurance Industry in the Selected OECD Countries with Three-Stage DEA Model**
Biwei Guan

In recent years, efficiency measurement has been widely used in the insurance industry. In this paper, we use the three-stage data envelopment analysis model to evaluate the efficiency value of 10 life insurance markets from OECD and make a comparison of them. In the second stage, we use stochastic frontier analysis slack regression to remove the impact of environmental effects and statistical noise on the efficiency value. The environmental variables we select are insurance density, market share, and growth of GDP. After the adjustment, the biggest change in input variables is the number of companies. We find the environmental factors have little effect on the German life insurance market but have a heavy effect on Belgium and Greece. And in future research, we will take more markets as observation targets and apply the efficiency value obtained to the deeper fields related to the insurance market.

■ TB-21

Tuesday, 10:30-12:00 - Virtual Room 21

Agent-Based Computational Management Science

Stream: Behavioral Modelling
Invited session
Chair: *Friederike Wall*
Chair: *Stephan Leitner*

1 - **The Insight Generation and Transfer of Learning' in Agent Based Modelling: An Experimental Study**
Hilya Mudrika Arini, Nurul Lathifah, Laela Dewi Maharani

This study aims to: (i) identify the difference between Agent Based Model (ABM) users and non-users in generating insight, and (ii) capture and distinguish the ability of ABM user and non-users in conducting transfer of learning from modelling a particular system to another similar system. In this study, ten ABM users and ten ABM non-users were participated in the experiment. The ABM users are students who have taken class of ABM with minimum score is B; whilst ABM non-users are students who have not studied about ABM but familiar with the system used in case study. In the experiment, the students were asked to analyse and solve a problem about HIV model provided in NetLogo software library. The students were asked to develop some scenario and fulfil the targets given at the beginning of the experiment in a certain time limit. Generally, this study found that ABM can support its users in generating insight and understanding problem clearly. Moreover, from this study, the ABM users tend to generate insight more frequently than ABM non-users during problem solving process. It was indicated by a higher score and variation of task duration, a higher number of scenarios, a higher scenario rate, and a higher average result of scenario of ABM users. The result from this study also depicted that after trying to solve a HIV problem using ABM model, 95% of participants were able to analogize COVID-19 problem with the HIV model.

2 - Longitudinal effects of recommendation strategies: an agent-based simulation approach

Nada Ghanem, Dietmar Jannach, Stephan Leitner

Recommender systems are widely used applications in practice, such as media streaming. The academic literature almost explores recommender systems from the consumers' perspective by optimizing towards their utilities. However, this one-sided focus might affect other stakeholders' interests since their objectives might be conflicting. We build an agent-based model to test the long-term effects of predominant recommendation strategies. In particular, we model recommendation providers that do not take a one-sided perspective but are interested in increasing their profit without compromising consumer satisfaction. Consumers receive a personalized list of products (i.e., movies) from the service provider. We assume that recommending products that increase the consumer's utility leads increases consumer satisfaction and consumption. In contrast, putting more emphasis on the recommended products' profitability might decrease consumption. However, the consumers' decisions are not only affected by the provided recommendations, but consumers learn from their experiences with the recommendation provider and opinions shared via social media. The initial results show that optimizing the recommendation towards the consumers' utilities doesn't necessarily increase the profit. Moreover, recommending products while balancing the utilities of consumers and the service provider decreases consumers' trust.

3 - Agent-based model calibration using retweet social network

Pierluigi Vellucci, Loretta Mastroeni, Maurizio Naldi

In the mathematical model describing the interactions among agents, calibration allows us to obtain realistic expectations about a social group's behaviour by setting the parameters governing those interactions. In this paper, we propose a method to calibrate agent-based models for opinion formation, considering data extracted from an online social network, namely Twitter. We measure the influence by the frequency of retweeting, making our methods applicable to any social network where reposting of opinions is allowed. This allows obtaining the influence coefficients in the ABM by direct inspection of the social network graph's weighted adjacency matrix. Our major original contributions can be summarised as follows: • we propose a calibration method that relies on the adjacency matrix in an online social network; • starting from a taxonomy of agent-based models, we provide a systematic assessment of the applicability of this calibration method; • we demonstrate its application using Twitter opinions on wind power; • for that specific context, we show that most influence coefficients (76%) result to be zero, and very few agents (less than 5%) exert a strong influence on other agents; • for that specific context, we show that any agent's influence is limited to one other agent in most cases so that the matrix of influence coefficients is sparse.

4 - Social norms and incentive schemes in organizations

Ravshanbek Khodzhimatov, Stephan Leitner, Friederike Wall

Many organizations face complex and often highly interrelated problems. As a result, tasks allocated to workers result in externalities, i.e., the actions taken by one worker often spill over to other workers' areas. To deal with this problem, organizations often employ incentive schemes based on team performance that encourage workers to coordinate their decisions. However, social dynamics within organizations, such as social norms that represent socially accepted behavior, might interfere with incentive schemes. Previous research suggests that individuals in organizations want to maximize their performance-based income and want to comply with social norms at the same time. We propose an agent-based model where agents perform a set of interdependent actions and share information regarding their past actions with their colleagues. From this shared information, agents learn what behavior is socially acceptable. The results suggest that incentives based on team performance work well when there are externalities across tasks assigned to agents. However, if the interdependencies are concentrated within tasks assigned to a single agent, team-based incentives negatively affect performance. We also find that organizational performance drops in the presence of social norms, which is more pronounced if team-based incentives are employed. Finally, as the task environment's complexity increases, the effect of social norms on performance decreases.

■ TB-22

Tuesday, 10:30-12:00 - Virtual Room 22

Bilevel stochastic optimization and related topics

Stream: Bilevel Optimization
Invited session
Chair: *Matthias Claus*
Chair: *Johanna Burtscheidt*

1 - Optimality Conditions in Risk-Neutral Bilevel Stochastic Linear Programming

Matthias Claus, Johanna Burtscheidt, Stephan Dempe

We consider risk-neutral bilevel stochastic linear programs with random lower level right-hand side, examine analytical traits of the arising expectation functional and provide optimality conditions in terms of generalized Hessians.

2 - A Pessimistic Bilevel Problem for Elastic Shape Optimization under Stochastic Uncertainty

Josua Sassen, Johanna Burtscheidt, Matthias Claus, Rüdiger Schultz

In this talk, we will translate a bilevel stochastic optimization approach, as used in economy-driven decision making, to a mechanical shape optimization problem. In this mechanical setting, the leader decides on an optimal material distribution on a thin elastic object to minimize a tracking-type cost functional while the follower chooses forces from an admissible set to maximize a compliance objective. The material distribution is considered to be stochastically perturbed in a construction phase between the two decisions. To model this, we consider pessimistic bilevel stochastic programs in which the follower maximizes over a fixed compact convex set a strictly convex quadratic function, whose Hessian depends on the leader's decision. The resulting random variable is evaluated by a convex risk measure. In theoretical considerations, we can show existence of optimal solutions under assumptions including real analyticity of the lower-level goal function. Furthermore, we discuss an alternate model where the leader hedges against optimal lower-level solutions and show that in this case solvability can be guaranteed under weaker conditions both in a deterministic and in a stochastic setting. Through extensive computational results, we will illustrate the bilevel optimization concept and demonstrate the effect of the interplay of follower and leader in shape design.

3 - Risk Averse Bilevel Programming under Stochastic Uncertainty
Johanna Burtscheidt, Matthias Claus, Josua Sassen
Stochastic bilevel problems arise from the interplay between two decision makers on different levels of hierarchy where the lower level problem is entered by a random vector. In our context, this models production errors of a shape or truss that has to be optimized due to possible acting forces.

We present a deterministic formulation for a bilevel problem under stochastic uncertainty which is based on special risk measures. In particular, structural properties and qualitative stability of the optimal value function of this model will be investigated.

4 - Welfare-maximizing transmission capacity expansion under uncertainty and imperfect competition
Sonja Wogrin, Diego Tejada, Anthony Downward, Andy Philpott
We apply the JuDGE optimization package to a multistage stochastic leader-follower model that determines a transmission capacity expansion plan to maximize expected social welfare of consumers and producers who act as Cournot oligopolists in each time period. The problem is formulated as a large-scale mixed integer program and applied to a 5-bus instance over scenario trees of varying size. We compare model results for three different cases: assuming a perfectly competitive market; considering one coal monopolist in the market; or assuming a Cournot oligopoly. This allows us to show the impact of imperfect competition on transmission expansion. We also present some computational results comparing JuDGE with solving the deterministic equivalent mixed integer program using a state-of-the-art integer programming package.

■ TB-23

Tuesday, 10:30-12:00 - Virtual Room 23

Global and Local Derivative-free Optimization Under Uncertainty

Stream: Derivative-free Optimization
Invited session
Chair: *Miguel Munoz Zuniga*
Chair: *Delphine Sinoquet*

1 - Chance Constraint Optimization of a Complex System: Application to the Fatigue Design of a Floating Offshore Wind Turbine Mooring System
Alexis Cousin
The industrialization of recent Floating Offshore Wind Turbine technologies requires efficient methodologies to find a design optimizing the cost of specific added components, in particular the mooring system ensuring station keeping while respecting a series of constraints for reliability. These constraints inherit the random characteristic of the environmental conditions, of the material properties, and of the manufacturing uncertainties. We investigate here constraints expressed as threshold crossing of maxima or time average of stochastic processes. We therefore face an optimization problem with a deterministic cost function and several probabilistic constraints with small failure probabilities. Moreover, the constraints are computed with a black-box model without access to analytical derivatives.

To palliate to the difficulty of small failure probabilities evaluation at each loop of the optimization, we propose first a more suitable reformulation of the constraints based on the Extreme Value Theory. We then solve the reformulated problem with a new algorithm based on surrogates sequentially improved during the optimization: AK-ECO. Expensive functions contained in the constraints are replaced by kriging models. Then, during each optimization cycle, the metamodels are sequentially improved and the approximated problem solved with a derivative-free optimization algorithm.

2 - RBF Surrogate Global Optimization of Homogeneously Noisy, Expensive Functions
Christine Shoemaker, Yichi Shen

Evaluation of a noisy function f(x) returns a value f(x)+ϵ where ϵ is a random variable with variance σ, and f(x) is the mean value of the function. Our algorithm focuses on computationally expensive functions f(x) so the number of objective function evaluations for different x is quite limited. To reduce the number of function evaluations required to solve the problem accurately, an RBF surrogate approximation (based on previously evaluated values of the function f(x)) is created. The variance σ(x) is unknown, but the variance is equal for all x (e.g. "homogeneous noise"). A noisy objective is very challenging because it may be necessary to evaluate expensive f(x) more than once at the same x to get a sufficiently accurate estimate of f(x). Our algorithm determines which points should be re-computed dynamically as the search continues. We focus on optimization of multimodal, computationally expensive continuous noisy functions f(x) with the assistance of a Radial Basis Function (RBF) surrogate approximation of f(x). This RBF surrogate is used to help guide the optimization search to reduce the number of objective function evaluations required. So,the proposed TRIM algorithm decides iteratively where to sample next and decides when and where to make repeated evaluations at a previously evaluated points. The results outperform Bayesian Optimization methods ISSO and EQI for noisy functions on test problems and can be more flexible in the choice of objective function.

3 - Multi-objective Bayesian Optimization of Noisy Simulators
Mickael Binois

Stochastic computer models present a series of unique challenges compared to their deterministic counterpart. With low signal-to-noise ratios, many runs are necessary to identify quantities of interest, making direct estimation too prohibitive even for moderate evaluation times. In the case of multi-objective optimization, this is exacerbated since we aim at finding the Pareto front, the set of optimal compromise solutions. Relying on Gaussian process emulators adapted to heteroscedastic noise, with parallel computing in mind, we propose an efficient batch sequential design strategy balancing replication and exploration. We illustrate the proposed method on various test problems.

■ TB-24

Tuesday, 10:30-12:00 - Virtual Room 24

Vector and Set Optimization I

Stream: Vector and Set Optimization
Invited session
Chair: *Elena Molho*
Chair: *Lidia Huerga*

1 - Optimality results for a class of nondifferentiable multiobjective programming problems with vanishing constraints
Tadeusz Antczak

A particular form of a mathematical programming problem which attracted the attention of the optimization community over more than the past decade is a so-called optimization problem with vanishing constraints. This is a consequence of the fact that an optimization problem with vanishing constraints has been served as a model for many problems from structural and topology optimization. In the most of works in the literature, optimality and duality results only for differentiable scalar optimization problems with vanishing constraints have been established. Our considerations are devoted to investigate optimality results for nondifferentiable vector optimization problems with vanishing constraints. We derive both necessary and sufficient optimality conditions for a new class of such nonsmooth extremum problems.

2 - Solving bi-objective linear programmes with Benders decomposition
Ali Sohrabi, Andrea Raith, Richard Lusby

Two algorithms are presented to solve bi-objective linear optimization problems with Benders decomposition. Firstly, the Benders decomposition technique is integrated with the bi-objective simplex algorithm: The original problem is decomposed into a Benders master problem (BMASTER), which contains y variables, and two extra variables $thetas$ that capture objective function values associated with a bi-objective Benders subproblem (BSUB), containing x variables of the original problem. The algorithm first minimizes the first objective function using standard Benders decomposition. Then, the parametric simplex algorithm is employed to iteratively find a new non-dominated point. The corresponding efficient solution $y*$ is used to solve BSUB. If BSUB is infeasible, a feasibility cut is added to BMASTER; otherwise, the parametric simplex algorithm solves BSUB to generate a set of optimality cuts. This iterative process continues until the last non-dominated point (optimal for the second objective function) is found. In the second algorithm, in each iteration, a weighted Benders problem is solved. Based on cuts generated by the weighted Benders, a new weight $lambda$ is calculated to find the "next" non-dominated point. This process also iteratively continues until all non-dominated points are found. We will show some initial computational results and discuss future work.

3 - Stochastic variational problems: from scalar to vector case
Domenico Scopelliti

In many real-life applications, the decision-maker has to make sequential decisions under uncertainty. To capture the dynamics that are essential to stochastic decision processes in response to an increasing level of information, Rockafellar and Wets introduced a multistage extension, in a stochastic framework, of a variational problem. This talk aims to describe this new formulation and to introduce some equilibrium problems studied with it. In this way, a vector generalization of these stochastic variational problems will be provided and analyzed as a natural extension.

4 - Robustification and scalarization of a parametric vector optimization problem: a noncomponentwise approach
Elena Molho, Elisa Caprari, Lorenzo Cerboni Baiardi

The simplest way to introduce robustness in a parametric multiobjective optimization problem is to consider the worst case scenario on each component of the vector-valued objective function. This approach is unduly pessimistic when there is dependence among the uncertainties that affect distinct component of the objective function. Some alternative notions of robust efficiency are based on a reframing of the original problem into a deterministic set-valued optimization setting where the upper quasiorder relation among sets is considered. Under this approach, we study the commutativity of robustification and scalarization by considering the equivalence of the solutions of the scalarization of the set-valued robust counterpart of the uncertain vector optimization problem with the robust counterpart of the scalarization of of the same problem.

■ TB-25

Tuesday, 10:30-12:00 - Virtual Room 25

Advances in Data-driven Decision-making under Uncertainty and its Applications

Stream: Stochastic and Robust Optimization
Invited session
Chair: *Juan Miguel Morales*

1 - Reliable Frequency Regulation through Electricity Storage: An Analytical Solution
Dirk Lauinger, François Vuille, Daniel Kuhn

Primary frequency regulation is an insurance contracted by electricity grid operators against unforeseen supply and demand mismatches. We formulate a receding-horizon optimization problem in continuous time that maximizes the expected profit of an energy storage operator selling this insurance under EU delivery guarantees. Undesired end-of-horizon effects are mitigated by a constraint on the energy reservoir's expected terminal state-of-charge. The losses during charging and discharging render the optimization problem and in particular the constraint on the expected terminal state-of-charge non-convex. The higher the spread of the mismatch distribution, the more pronounced the influence of the losses. We derive a data-driven analytical solution based on the empirical mismatch distribution and the charging and discharging losses.

2 - Hierarchical clustering for energy systems planning: A two-phase framework based on data classification and time-shifting-sensitive discrepancy measurement
Lucas Condeixa, Fabricio Oliveira, Afzal Siddiqui

Decision making in energy systems has gradually developed to enable integrating different sub-systems and variable renewable energy resources to plan future electricity grids. Nonetheless, models trying to combine numerous operating scenarios, an overarching geographical scope, and long-term planning horizons can be computationally intractable. We aim to improve the clustering of stochastic sources of data (e.g., wind and solar availability) in strategic electricity systems planning.

Energy systems modelling approaches overlook the consequences of using aggregated time series in long-term planning, such as capacity and renewable energy use estimation errors. Our main contribution is an integrated clustering and optimisation framework for the generation, transmission, and storage expansion planning. The proposed framework is divided into two phases. First, we classify critical points in the historical time series to form representative days, which are used to find the system's optimal capacity. Second, we use hierarchical clustering to optimise the operational outcome. In particular, we further improve data representation by using the Wasserstein distance to account for the discrepancy between clusters. Results for a representative power system show significant improvement compared to other clustering methods in the accuracy of key metrics such as total system costs and renewable energy production levels.

3 - Robust and Distributionally Robust Optimization Models for Support Vector Machine with Medical Applications
Daniel Faccini, Francesca Maggioni, Florian Potra

In this talk we present novel data-driven optimization models for Support Vector Machine (SVM), with the aim of linearly separating two sets of points that have non-disjoint convex closures. Traditional classification algorithms assume that the training data points are always known exactly. However, real-life data are often subject to noise. To handle such uncertainty, we formulate robust models with uncertainty sets in the form of hyperrectangles or hyperellipsoids, and propose distributionally robust optimization models enforcing limits on first-order deviations along principal directions. All the formulations reduce to convex programs. The efficiency of the new classifiers is evaluated on real-world databases in medicine, requiring cancer detection and heart disease recognition. Experiments show that box robust classifiers might be overly-conservative, whereas higher levels of accuracy can be achieved when moments of the distributions are assumed exploiting the available information via distributionally robust optimization methods.

4 - Distributionally robust optimization with side information based on probability trimmings and optimal transport
Adrián Esteban-Pérez, Juan Miguel Morales

We deal with stochastic programs conditional on some covariates, where the only information on the relationship between these covariates and the input parameters of the stochastic program is reduced to a finite data sample of their joint distribution. We take advantage of the close link between the notion of trimmings of a probability measure and the partial mass transportation problem to construct a data-driven Distributionally Robust Optimization framework that hedges the decision maker against the intrinsic error in the process of inferring conditional information from limited joint data. We show that our approach naturally leads to distributionally robust versions of some local nonparametric predictive methods, such as Nadaraya-Watson kernel regression and K-nearest neighbors. Finally, we consider several applications to illustrate our approach.

■ TB-26

Tuesday, 10:30-12:00 - Virtual Room 26

Software for LP/MIP

Stream: Software for Optimization
Invited session
Chair: *Timo Berthold*

1 - What's New in Gurobi 9.1
Michael Winkler

We will talk about the enhancements, features and performance improvements in our Gurobi 9.1 release. In particular we will present our new MIP heuristic for models with extremely difficult LP relaxations, the Irreducible Infeasible Subset of constraints (IIS) algorithm and its improvements, numerical improvements to avoid trickle flows, and also talk about the speed-ups that we achieved in our MIP, LP and QP algorithms.

2 - Recent developments in the FICO Xpress-Optimizer
Timo Berthold

We will present what is new in the linear, mixed-integer, and non-linear programming solvers within FICO Xpress Optimization.

3 - Introduction to Cardinal Optimizer
Qi Huangfu

The Cardinal Optimizer, or COPT, is a relatively new optimization software. In this talk, I will give a general introduction to COPT, including its solvers and modelling interfaces. I will talk about some rather challenging LP models that we managed to solve. I will also share the progress of our MIP solver development.

4 - Presolving and Postsolving Linear Programming Problems
Philipp Christophel, Imre Polik

Presolving (sometimes called Preprocessing) of linear and mixed integer programming problems has been a part of solver software for many decades. This talk will highlight some intricacies that need to be considered when presolving linear programming problems. Especially for simplex-based solvers, special care needs to be taken in the pre- and postsolving phase to ensure that a valid basic solution is returned that can be used for warmstarting. We will also discuss presolve techniques that became more relevant recently and how they impact the overall importance of LP presolving.

■ TB-27

Tuesday, 10:30-12:00 - Virtual Room 27

Data Science and Analytics - Applications 1

Stream: Data Science and Analytics (contributed)
Contributed session
Chair: *Monisha Bhattacharya*

1 - Large-Scale Process Monitoring
Volker Kraft

Statistical process monitoring (SPM) concerns the retrospective review of process performance to guide subsequent action and is one of the cornerstones of quality control in manufacturing and beyond. Typically, though, SPM relates to a small number of processes, both in its supporting literature and in actual practice. However, in a modern manufacturing plant, there may be thousands of process measurements worth monitoring. Furthermore, with initiatives like Industry 4.0 and a prevailing climate of 'big data' promising dramatic increases in the availability of time-based data, this number will escalate rapidly.

In this session, attendees will see how to 'scale up' SPM to this new reality. All JMP demonstrations and additional learning resources will be made available to participants. A fully functional thirty-day trial version of JMP can be downloaded from www.jmp.com/trial if required.

2 - Hourly Temperature Data do not support the Views of the Climate Deniers, Sceptics, and Trivializers: Evidence from Barrow Alaska
Kevin Forbes

According to the IPCC, it is extremely likely that human activity has been the dominant cause of the observed increase in global temperatures since the mid-20th century. This view has been endorsed throughout the scientific community. In contrast, recent polling data has indicated that a significant percentage of the population does not fully embrace this consensus. This paper assesses whether the hourly temperature data supports this scepticism using data from the Barrow Atmospheric Observatory in Alaska. At this observatory, the annual average temperature increased by 5.8 oC between 1985 and 2019. A model to explain hourly temperature was formulated using data representing CO2 concentrations, the hourly level of total downward shortwave irradiance, variables to control for seasonality, and variables to reflect the possible contribution of other factors. The model also includes an ARCH/ARMA specification to control for the data's heteroskedastic and autoregressive nature. The model was estimated using hourly data for the period 1 Jan. 1985 through 31 Dec. 2015. The results are consistent with the scientific consensus. The model was evaluated using out-of-sample hourly data over the period 1 Jan. 2016 through 31 Aug. 2017. Consistent with causality, the out-of-sample predictions are more accurate if the estimated effects of CO2 are included in the prediction equation.

3 - Minimizing Bias in AI based recommender systems
Monisha Bhattacharya, Shantanu Biswas, Saikat Chakraborty, Gunjan Bansal

Artificial Intelligence has been widely explored and has found application in various recommender systems. AI systems are being used to tailor and personalize recommendations in various domains such as entertainment, education, e-commerce to name a few.

Although AI algorithms can be highly accurate in their predictions, they are liable to be biased. And, therefore it is an ethical responsibility of the AI solution providers to be careful to minimize bias and ensure fairness. In this paper, we study fairness in recommender systems. We have formulated a combinatorial optimization problem that minimizes bias in the already existing machine learning models.

We have tested our method on a number of standard datasets and evaluated different fairness notions. We have shown that our method outperforms or performs equally well as compared to existing approaches.

■ TB-28

Tuesday, 10:30-12:00 - Virtual Room 28

Machine Learning and Optimization: new challenges, applications and objectives II

Stream: Mathematical Optimization and Data Science
Invited session
Chair: *M. Asuncion Jimenez-Cordero*

1 - Improving the interpretability of linear models with categorical predictors
Marcela Galvis Restrepo, Dolores Romero Morales, Emilio Carrizosa

In this talk, we study Generalized Linear Models in the presence of categorical predictors and their interactions. The traditional one-hot encoding, where each category is represented by a dummy variable, can be wasteful, difficult to interpret, and prone to overfitting, especially when dealing with high-cardinality categorical predictors. We propose a methodology that finds a reduced representation of the categorical predictors by clustering their categories. This is done through a Greedy Randomized Adaptive Search Procedure which aims to preserve (or even, improve) accuracy, while reducing the number of coefficients to be estimated for the categorical predictors. Having fewer coefficients to estimate allows to select and interpret a model with interactions between the merged categories with lower standard errors compared to a model that includes interactions between the original dummies. We illustrate the performance of our approach in both simulated and real-world datasets.

2 - Empirical analysis of some fuzzy-valued trimmed means based on depth measures
Beatriz Sinova

Fuzzy data provide a very useful tool for modelling the imprecise information that is obtained from many real-life random experiments. Therefore, its presence is growing in fields such as Engineering, Biomedicine, Psychology, etc. and the range of statistical techniques suitable for their analysis is also increasing. In particular, different location measures have already been adapted in order to describe the central tendency of a fuzzy-valued dataset. Some notions of medians, M-estimators of location and empirical trimmed means have been analysed and compared in the literature. Due to the good results of the latter alternative, it would be interesting to tackle other possibilities to define trimmed means for fuzzy-valued data, such as depth-based trimmed means. This approach is common in the context of functional data analysis, hence this study focuses on the empirical behaviour of trimmed means that evaluate the depth of a fuzzy-valued datum on the basis of its identification with a function.

3 - Cost-aware Constraint Screening for the Unit Commitment Problem
Álvaro Porras Cabrera, Salvador Pineda Morente, Juan Miguel Morales, M. Asuncion Jimenez-Cordero

In an attempt to speed up the solution of the unit commitment (UC) problem, both machine-learning and optimization-based methods have been proposed to lighten the full UC formulation by removing as many superfluous line-flow constraints as possible. While the elimination strategies based on machine learning are fast and typically delete more constraints, they may be over-optimistic and result in infeasible UC solutions. For their part, optimization-based methods seek to identify redundant constraints in the full UC formulation by exploring the feasibility region of an LP-relaxation. In doing so, these methods only get rid of line-flow constraints whose removal leaves the feasibility region of the original UC problem unchanged. In this paper, we propose a procedure to substantially increase the line-flow constraints that are filtered out by optimization-based methods without jeopardizing their appealing ability of retaining feasibility. Our approach is based on tightening the LP-relaxation which the optimization-based method uses with valid inequalities related to the objective function of the UC problem and hence, of an economic nature. The result is that the so strengthened optimization-based method not only identifies redundant line-flow constraints, but also inactive ones, thus leading to more reduced UC formulations. We illustrate the boosting properties of our approach on realistic instances of the UC problem.

4 - Data-driven prescriptive scenario selection with applications in power markets: Retailer's optimal trading
Alberto Corredera, Carlos Ruiz

We present a data-driven framework for optimal scenario selection in stochastic optimization with applications in power markets. Similar to the approach by Bertsimas and Kallus 2020, the proposed methodology relies in the existence of auxiliary information and the use of Machine Learning(ML) techniques to narrow the set of possible realizations (scenarios) of the variables of interest. However, we extend this setting by implementing a novel validation algorithm that allows optimizing each ML hyperparameters to further improve the prescriptive power of the resulting set of scenarios. Several supervised and non-supervised ML techniques are examined, including KNN, KMeans and Decision Trees. We test the proposed methodology in a realistic power market application: optimal trading strategy (forward + spot) for an electricity retailer under uncertain spot prices. Results indicate that the retailer can greatly benefit from the proposed data-driven methodology and improve its market performance. Moreover, we perform and extensive set of numerical simulations to show how the best ML hyperparameters in terms of prescriptive performance differ greatly from those that provide the best predictive accuracy.

■ TB-29

Tuesday, 10:30-12:00 - Virtual Room 29

AI Approaches for Decision Making under Uncertainty

Stream: AI and Decision Making
Invited session
Chair: *Pascale Zaraté*

1 - Modelling endogenous long term climate uncertainty using decision programming
Olli Herrala, Tommi Ekholm, Fabricio Oliveira

As more powerful computers and solution methods have been introduced, optimization under endogenous uncertainty has become a relevant topic in decision-making research. Research on endogenous uncertainty has focused on two main types, the first one being decision-dependent uncertainties. A novel framework called Decision Programming is based on converting an influence diagram representation of a problem to a mixed-integer linear programming problem. This allows for solving problems with decision-dependent uncertainties using off-the-shelf solvers.

This research extends Decision Programming to accommodate the other fundamental type of endogenous uncertainty: conditional information revelation. In multi-stage stochastic programming (MSSP) problems, (conditional) non-anticipativity constraints are used to model such uncertainties, and we apply them to Decision Programming. This allows us to consider uncertainties that encompass both types simultaneously, something that existing frameworks have been unable to do.

The extended framework is applied to two example problems. The first example is a water resources planning problem considering optimal scheduling for building reservoirs in a river basin. The second example is a large-scale cost-benefit optimization problem for finding the climate change mitigation strategy that minimizes the expected sum of mitigation costs and climate damages. Neither of these example problems could be solved with other existing frameworks.

2 - Goal Programming models with interval coefficients for the sustainable selection of marine renewable energies
Negar Akbari

In this paper, a strategic decision making model for the sustainable development of marine renewable energy is proposed, and a specific application to the United Kingdom (UK) is demonstrated. As an island nation the UK benefits from significant marine energy potential which is providing an increasing contribution to UK's renewable energy portfolio. The paper investigates the question of how decision makers can be aided to reach a decision on which types of marine renewable energy projects should be chosen for development given that strategic energy planning is subject to a number of uncertain parameters and multiple sustainability objectives. In this context, the contribution of this paper lies in the combination of renewable energy portfolio selection and the application of multi-objective methods. Interval coefficient goal programming models are adopted in order to address the impreciseness and uncertainty associated with the goals and coefficients of the models in the context of renewable energy selection. The potential renewable energy projects are clustered in order to aid the decision making process and preferential weight sensitivity methods are employed. Conclusions are drawn for optimistic and pessimistic scenarios in the context of UK marine renewable energy planning.

3 - A Hybrid Algorithm to Schedule Electric Vehicles in Mobility-On-Demand Schemes
Emmanouil Rigas, Nick Bassiliades, Sarvapali Ramchurn

We study a setting where Electric Vehicles (EVs) operate within a Mobility-on-Demand scheme. Such schemes have the ability to increase vehicle utilization, as one vehicle is used by multiple commuters and decrease the environmental impact. In the proposed scheme, EVs are distributed across a set of stations and customers request trips between pairs of stations at a particular point in time. We propose scheduling algorithms which take as input the trip requests and calculate the EV-to-customer assignment, aiming to maximize the number of executed trips. Initially, we solve the problem offline and optimally using Mixed-Integer-Programming techniques. This algorithm is observed to have average scalability, as its execution time is reasonable for settings with up to a few tenths of stations and EVs and a few hundreds of requests. Thus, we extend this solution by developing a hybrid algorithm where on top of the trips scheduled offline, it also handles requests that arrive in real time. This algorithm uses a heuristic search mechanism that considers the sum of squares of all EVs in all stations to decide on whether to execute a trip, assuming EV availability exists. In the case of the hybrid algorithm, in order to guarantee the feasibility of the already scheduled trips, we use a set of relocation drivers for moving the EVs to different stations if needed. To cope with the EVs' limited range we use fast battery charging, giving emphasis in the utilization of renewable energy.

■ TB-30

Tuesday, 10:30-12:00 - Virtual Room 30

MILP for energy efficiency and sustainability

Stream: Mixed Integer Linear Programming
Invited session
Chair: *Maurizio Bruglieri*

1 - Waste Collection Point Location and Allocation Model with Hierarchical Clustering
Adam Viktorin, Dušan Hrabec, Radovan Šomplák, Vlastimír Nevrlý

Recycling is a crucial part of environmental sustainability, and the European Union sets regulations and waste recovery targets that should be met in the near future. The cities face the challenge of optimizing investments into waste management to meet the EU standards while maintaining economic affordability. One of the issues is the optimal collection points location for specialized waste that is still not properly recycled (e.g., fat and cooking oil containers, metallic waste containers). The main target is to find the lowest number of collection points that would still attain the waste production, and the average walking distance to the waste container would be kept beneath the tolerable distance for citizens. The population density and waste production vary over city parts, and thus, the need for specialized containers in more populated city centers, industrial zones, or household streets varies as well. The purpose of this work is to develop a robust generalized decision-support tool for waste collection points location and allocation. This task leads to a mixed-integer linear program which would be unsolvable for larger cities in a reasonable time. Therefore, hierarchical clustering is utilized for simplification of the model, and the resulting framework is tested on several case studies - waste allocation for county seats of the Czech Republic.

2 - A new ILP Model for a Line Balancing Problem with Minimization of Power Peak
Paolo Gianessi, Xavier Delorme

Encouraged by the growing concern of industry for energy efficiency, several recent research works have emerged that focus on energy constraints and/or optimization criteria (mostly in relation to energy consumption, energy cost and power peak) in production systems. However, as far as we are aware of, very few works exist that consider energy at the design stage of a production system, e.g. for the Simple Assembly Line Balancing Problem (SALBP). SALBP is a classical NP-hard problem in which tasks with given execution times and precedence relations must be assigned to the workstations of a paced assembly line so as to minimize either the cycle time or the number of workstations. In this work we study the recently introduced SALBP with Power Peak Minimization (SALB3PM), where tasks also feature a constant power consumption: to smoothen the power consumption profile, the minimization of the overall power peak over a production cycle is sought for. SALB3PM generalizes SALBP since scheduling decisions add to the core balancing decisions, and is hence NP-hard as well. We propose a novel 0-1 Linear Programming formulation for SALB3PM based on three sets of binary two-index variables that respectively: represent the assignment of a task to a workstation; assert whether two tasks are assigned to the same workstation; model the trigger of task at a given date. Problem-specific valid inequalities and some additional preprocessing are presented, and numerical results are discussed.

3 - Routing a Mixed Fleet of Electric and Traditional Vehicles with Congestion Charge Areas
Maurizio Bruglieri, Bülent Çatay, Merve Keskin, Simona Mancini, Ornella Pisacane

Freight transport is one of the sectors with the greatest impact on environmental pollution. In fact, transport companies are currently incentivized to use Electric Vehicles (EVs) that can guarantee a substantial reduction of air and noise pollution. Moreover, a company can also take advantage of a free access to the Congestion Charge (CC) area, usually the city center, where an Internal Combustion Engine Vehicle (ICEV) is not allowed to enter for most of the day unless a toll is paid. However, the EVs are more expensive than ICEVs; hence, it will be more convenient and realistic for a company to use a mixed fleet. This work aims to determine the fleet composition and devise the routes of EVs and ICEVs which are subject to different fuel costs. In addition, a toll is paid when an ICEV enters the CC area. Due to their limited driving range, the EVs may need to recharge their batteries en-route at recharging stations in order to continue their routes. Each vehicle departs from a common depot and returns to the same depot within a maximum time. In addition, each customer is associated with a prespecified time window. We propose arc-based and route-based Mixed Integer Linear Programming formulations for this new vehicle routing problem and develop an Adaptive Large Neighborhood Search method to solve it. We carry out computational experiments using realistic instances based on Milan (Italy) road network and provide managerial insights.

4 - Dantzig-Wolfe decompositions with linking variables
Stefan Ropke, Jens Vinther Clausen, Richard Lusby

We study Dantzig-Wolfe decomposition applied to integer linear programming problems (ILPs). Dantzig-Wolfe decomposition is normally applied to ILPs by selecting a set of coupling constraints whose removal makes the remaining constraints decompose into several independent sub-problems. In this talk, we also consider linking (or coupling) variables such that both variables and constraints can be removed from the problem in order to reach a form where the remaining variables and constraints decompose into several independent sub-problems. Several successful applications of this form of Dantzig-Wolfe reformulation have been published in the past decade.

Applying Dantzig-Wolfe decomposition to an ILP results in an alternative model that still contains integrality constraints. Relaxing the integrality constraints leads to the Dantzig-Wolfe relaxation. We show general families of valid inequalities that can be used to strengthen the Dantzig-Wolfe relaxation when the decomposition involves linking variables. These valid inequalities are of the non-robust type meaning that each added valid inequality complicates the sub-problem. If the original ILP and the chosen decomposition satisfy certain conditions then it can be shown that adding the valid inequalities to the Dantzig-Wolfe relaxation is enough to guarantee integer solutions. We present these conditions and show results from applying the theory to the Temporal knapsack problem.

■ TB-31
Tuesday, 10:30-12:00 - Virtual Room 31

DSS Applications -4

Stream: DSS
Invited session
Chair: *Jason Papathanasiou*

1 - Analysis of sustainable development diversified strategies to support decisions in transport sector
Aristi Karagkouni, Dimitrios Dimitriou

Global sustainability challenges are shaping the way business operates in the 21st century. Businesses are under increasing pressure from decision makers (e.g., stakeholder' shareholders, customers, employees, society) to assess their environmental and socioeconomic impacts and manage their actions with sustainable intent. The necessary condition, that is, ensuring economic, social and environmental sustainability, also affects the decision-making process of organizations and businesses in the transport sector, which, by promoting accessibility to productive services and connectivity to markets, is a key contributor to economic development. Investing in transport infrastructure projects, is a major concern in terms of the planning process and strategic analysis in order to achieve business resilience and sustainable development. Hence, planners and decision makers promote investments in transportation infrastructure projects in order to achieve socioeconomic and sustainability goals. This research deals with the evaluation of the key industry-shaping trends emerging that will shape sustainable transport towards achieving the United Nations' 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals. Conventional wisdom of this paper is to provide the framework of the analysis for the prioritization of valuable investments for the transport sector's sustainable transition, which is a major challenge for planners, managers and decision makers.

2 - Integrating Life Cycle Assessement and Multi Criteria Decision Making for Sustainable Selection of Packaging Materials
Meenu Singh, Ankit Kumrawat, Garima Agrawal, Millie Pant

Packaging plays an significant role in a product's saleability by providing a protective covering and increasing the product's face value. Depending on the type of product, packaging materials can range from glass to paper to tin to plastic in order to make the product appear appealing. However, at the hindsight, packaging materials pose severe environmental implications when the product has been consumed and the time is to dispose off the packing. As a result, green packaging has become particularly relevant for the packaging industries, as regulatory controls and environmental legislation have also been increased. This paper aims at developing a comprehensive decision making approach for identifying the sustainable packaging material based on several criteria. A hybrid approach, combining Life Cycle Assessment (LCA) and Multicriteria Decision Making (MCDM) methods is proposed to evaluate the various commonly used packaging products in context of Indian industries. Over all nine packaging products are considered viz. Glass Bottle, PET Bottle, LDPE Pouches, Jute Bag, Paper Bag, HDPE Bag, Paper Cups, PP Cups, and PP Woven Sacks. Based on Impact 2002+ method, eight Impact categories are considered, which are evaluated through LCA and are further used for the performance evaluation of these packaging materials as an initial MCDM data matrix. This hybrid approach provides a more systematic analysis of the sustainability of the packaging materials discussed in detail in the paper.

3 - Optimization of air conditioner configuration considering operating schedule
Takuma Shibata

In order to design an air conditioning system with high energy efficiency, it is required to process the heat load of a building without excess or deficiency. However, the heat load that air conditioners have to process depends on how they are operated. For example, while a peak heat load occurs at startup, it can be leveled out by cooling or heating the building in advance. When the heat load is equalized, it is possible to select equipment with a smaller capacity. For the above reasons, it is important to consider how the system will be operated when designing the air conditioner configuration. In this research, we will develop an algorithm to design an air conditioning system that considers the operating schedule.

4 - Resilient road network investment strategy with copula uncertainty quantification
Chence Niu, Sisi Jian, Divya Nair, Vinayak Dixit

Due to the frequent extreme events, it is of utmost importance to develop solutions to ensure transport infrastructure resiliency to disasters. In this paper, we present a novel solution method for the optimal road network pre-disaster investment strategy under different disaster scenarios. A bi-level multi-objective optimization model is developed. The objectives are to maximize the capacity-based performance and reliability of the road network which are measured by the resilience polygon area and minimize costs. The Shapley value is used to select the candidate edges and get an approximate optimal project order. The Google API data are used to explore the dependency between the different states with copula functions. The Frank copula is used to simulate the edge capacities under different disaster scenarios with 4 road types based on the fragility and recoverability matrix. Through the experimental study, we found that that the dependency between road capacities does affect reliability result. The optimal solution was obtained by exploring the Pareto Front. The investment strategy is significantly affected by the characteristics of the road edges and disaster scenarios. Especially in the case of moderate damage, the performance and stability of the road network cannot be improved at the same time. There would be specific critical sections (high fragility and low recoverability, such as mountain roads) that can significantly improve the overall performance of the network.

■ TB-32

Tuesday, 10:30-12:00 - Virtual Room 32

Decision aiding in resource allocation problems

Stream: Multiple Criteria Decision Analysis
Invited session
Chair: *Ozlem Karsu*

1 - Ensuring Multidimensional Fairness in Public Service
Damla Akoluk, Ozlem Karsu

We consider decision-making problems, in which decisions lead to distributions of multiple benefits to multiple users. We develop two mathematical modelling-based approaches that incorporate multidimensional efficiency and fairness concerns for such problems. We structure the problem using two alternative bi (multi)-objective programming formulations. The first one suggests a bi-objective programming model, which aggregates the multidimensional efficiency concerns in one objective and multidimensional fairness concerns in the other objective. In that sense, it explicitly focuses on the trade-off between these concerns. The second formulation defines the objective functions based on the type of benefit as the total social welfare obtained from a given benefit distribution. Each such welfare function is defined as a Schur-concave function and incorporates both efficiency and fairness concerns for the distribution of that benefit. This results in a n-objective model, where n is the number of benefit types considered. We illustrate and compare these approaches using examples of public service provision problems.

2 - Fair Resource Allocation using Welfare-Based Dominance Constraints
Ozlem Karsu, Nikolaos Argyris, Mirel Yavuz

We consider the problem of supporting resource allocation decisions affecting multiple beneficiaries. Such problems inherently involve efficiency-fairness trade-offs. We introduce a new approach based on the paradigm of maximizing efficiency subject to constraints to ensure that the decision is acceptably fair. We incorporate fairness in the form of welfare dominance, ensuring that the resultant distribution of benefits to beneficiaries is at least as good as some reference distribution with respect to a set of social welfare functions that satisfy commonly accepted efficiency and fairness related axioms. We introduce a practical means to parameterize the problem, which allows for excluding welfare functions that are deemed insufficiently or overly sensitive to inequality. We develop tractable reformulations for the resulting nonlinear multi-level optimization problems and demonstrate the potential use of the suggested framework on two case studies.

3 - Allocation of Personal Protective Equipment to Health Centers during Early Phases of a Pandemic
Bahar Yetis Kara, Zehranaz Donmez, Serkan Turhan, Ozlem Karsu, Oya Ekin-Karasan

We aim to establish a centralized fair and efficient allocation of surgical and respiratory masks to a set of hospitals given highly limited supply during the pandemic phase. The total number of infected workers and patients is minimized along with an inequity function on shortages. To this end, a multi-objective multi-period non-linear resource allocation model is formulated and optimally solved using epsilon-constraint algorithm. A customized genetic algorithm is proposed to obtain the approximate Pareto frontier. Additionally, rule-of-thumb policies are developed to be used by the decision makers and comparative analysis between these policies, heuristic, and optimal solutions are provided.

■ TB-33

Tuesday, 10:30-12:00 - Virtual Room 33

Local search and metaheuristics

Stream: Heuristic Optimization
Invited session
Chair: *Merve Uzuner Sahin*

1 - Development of a Local Search Method for a Large-Scale Generalized Assignment Problem
Yuto Yoshida

The generalized assignment problem is one of the representative combinatorial optimization problems with applications in a wide range of industrial and academic fields, and many exact and approximate solution methods have been proposed. However, with the development of information and communication technology in recent years, applications of generalized assignment problems based on large-scale data that cannot be handled by conventional methods, such as product recommendation on Web services, have emerged. The purpose of this research is to develop an algorithm that can efficiently obtain accurate solutions to the generalized assignment problem based on large-scale data, based on the local search method, which is one of the metaheuristics. Numerical experiments are conducted to confirm the effectiveness of the proposed method by comparing it with commercial optimization solvers and existing methods.

2 - Artificially Intelligent Evolutionary Algorithms in Designing Multi-Layered Supply Chain Networks: A Comparative Analysis
Sahar Validi

Designing a supply chain network is a complicated task and the overall performance of the supply chain is extremely affected by the structure of its logistics network. The complexity of designing a logistics network increases when the number of players involved and the layers within the network are increased. Designing and optimising such a complex network is a very challenging task that requires taking into account different criteria and conflicting objectives to satisfy all stakeholders. Facility Location with its wide range of integrated models combined with Multi-Criteria Decision Analysis techniques are two of the well-established subject areas in Operational Research that their applications in network design and optimisation are increasingly growing. Multi-layer integrated facility location problems are typically computationally NP-hard. Solving such complex combinatorial optimisation models often requires multi-phase solution approaches. Review of literature reveals that varieties of methods have been tested for this purpose yet the search for an efficient and generic solution method continues. This paper reports on an ongoing research on the effectiveness of artificially intelligent evolutionary algorithm-based heuristics, meta-heuristics and hyper-heuristics in solving multi-echelon integrated facility location problems.

3 - Ant Colony Optimization for the Network Alignment Problem
Guillem Rodríguez Corominas, Maria J. Blesa, Christian Blum

An alignment between two networks is a mapping between their respective nodes. The Network Alignment (NA) Problem asks to find an alignment such that the topological and functional structure is well preserved.

The goodness of an alignment can be quantified according to different measures. Some use functional information, while others focus solely on structural aspects. As a combinatorial optimization problem, the goal in the NA problem is to find an optimal alignment with respect to a given quality measure. As one may suspect, the problem is NP-hard.

Lately, many algorithms have been proposed to tackle the problem. However, they mainly focus on either obtaining a similarity score between the nodes and then greedily constructing the solution, or directly optimizing the given quality measure without taking into consideration the underlying topological information. In order to unify both trends, we propose AntNetAlign, an Ant Colony Optimization algorithm that uses similarity information from the input networks to guide the construction of solutions through a better search space.

We carried out an extensive experimentation, on a wider spectrum of benchmark instances than other works from the literature. The results show that, when compared to existing approaches, AntNetAlign outperforms those approaches in two out of three performance measures. Moreover, it provides balanced solutions, since they optimize both functional and structural alignment properties.

4 - Redundancy Allocation Optimization with Repairs: A Simulation-Based GA Approach

Merve Uzuner Sahin, Orhan Dengiz, Berna Dengiz

The high performance system design based on reliability optimization has been an active research area and attracting a great deal of attention of researchers. One of the most important problem in this area is to seek the redundancy allocation that either maximizes the system reliability subject to cost or minimizes the system cost subject to reliability. This problem is called redundancy allocation problem (RAP) and it is NP-hard. In such problems, computational requirement grows exponentially with increasing problem size. RAP is important for designing a new system especially for electronic devices, telecommunication systems and cloud server systems. Especially in cloud server systems used in IT field, a majority of the failures are attended by system professionals and DevOps teams that bring the failed servers back to running state. This way, after the repairs are completed, the system is back to being a redundant system which can allow another failure for one of the redundant components in the future. There is a need for a reliability calculation model to consider the repair of broken components to make more realistic designs. Therefore, to obtain the optimum RAP design for cloud server systems or similar systems that allow component repair after a failure incident, the Genetic Algorithm is integrated with the discrete event simulation model which is developed in this study. Results are compared with cases where components repairs are not considered in RAP optimization.

■ TB-34

Tuesday, 10:30-12:00 - Virtual Room 34

Networks and Assignment problems: properties and applications

Stream: Combinatorial Optimization
Invited session
Chair: *Ioannis Fragkos*

1 - Resource allocation under uncertainty in transportation networks

Ioannis Fragkos, Joris Wagenaar, Martin Faro

Logistics service providers (LSP) utilize transportation assets such as car wagons and containers in order to service customer demand. Servicing such demand implies that assets of appropriate capacity should be utilized for the transportation operation. The amount of time required for transportation operations can be affected by network disruptions and is therefore stochastic. This gives rise to a generalized newsvendor problem, where the LSP decides how many assets to acquire and how to schedule them so that stochastic demand requests that require specific capacity but uncertain time are fulfilled. Excess demand can be satisfied by utilizing spot assets, which, however, come at a higher cost. We apply this framework to an LSP who leases train wagons on an annual basis and responds to demand fluctuations via ad-hoc spot train rentals and formulate this problem as a two-stage stochastic program. Structural properties of the formulation and a column generation-based procedure greatly reduce the search space of optimal solutions. Computational results illustrate the efficiency of our approach.

2 - The Stochastic Time Window Assignment Problem with Quadratic Penalties

Panagiotis Repoussis, Anastasios Vareias, Christos Tarantilis

This work presents a MIP model for the assignment of time windows to an ordered set of service requests with uncertain service durations modeled via continuous random variables. This problem occurs in various service delivery settings, such as district nursing and surgery scheduling. The goal is to minimize the expected service inconvenience. During a preprocess phase, the resulting stochastic waiting times and the probability distributions of the start service times are propagated throughout the service sequence. The model also employs probabilistic chance constraints to ensure reliable and consistent service. Various computational experiments are reported assuming different service levels and probability distributions for the stochastic service times.

3 - On Matchings, T-Joins, and Arc Routing in Road Networks

Thu Huong Dang, Adam Letchford, Burak Boyaci

Matchings and T-joins are fundamental and much-studied concepts in graph theory and combinatorial optimisation, with a wide array of applications. One important application of matchings and T-joins is in the computation of strong lower bounds for Arc Routing Problems (ARPs). An ARP is a special kind of vehicle routing problem, in which the demands are located along edges or arcs, rather than at nodes. In a recent project with real-life instances, we encountered large-scale ARPs, with over ten thousand edges. For these particular ARPs, matching techniques gave acceptable lower bounds, but used an excessive amount of both time and memory. We point out that the literature on applying matchings and T-joins to ARPs does not fully exploit the structure of real-life road networks. We show that one can dramatically reduce the amount of computational effort needed by matching techniques, without deteriorating the quality of the lower bounds, by exploiting the structure of real-life road networks. Moreover, any future improvements in matching software will make our procedures even better

4 - The dynamic unsplittable flow problem

Francois Lamothe, Alain Hait

The unsplittable flow problem is an extensively studied NP-hard variant of the classical maximum flow problem. In this problem, one is given a capacitated graph together with a family of commodities (origin, destination, demand). Each commodity has to route its demand on a unique path and the arc capacities must not be exceeded by the total flow. In this work, we consider a dynamic variant of the problem. A sequence of unsplittable flow problems is given, representing different time-steps. Each time-step introduces a few changes: some commodities change their origin or destination, some arcs are added or deleted. This problem features two conflicting objectives: 1) minimize the flow exceeding the capacities (overflow), 2) commodities must use the same path for consecutive time-steps if possible. The dynamic unsplittable flow problem can be expressed with several Mixed Integer Linear Programming (MILP) formulations. One of them must be solved through a column generation and was presented by Gamvros and Raghavan in 2012. They also proposed a method to solve the pricing problem which is more difficult than those present in classical flow problems. However, their procedure has some limitations and two new algorithms with a better worst-case complexity were found. The different formulations can be directly used in MILP solvers or serve as the basis for heuristics. Several solvers for the dynamic unsplittable flow problem were compared on a test-bed of small to large instances.

■ TB-35

Tuesday, 10:30-12:00 - Virtual Room 35

Topics in Combinatorial Optimization IV

Stream: Combinatorial Optimization
Invited session
Chair: *Eligius M.T. Hendrix*

1 - Solution methods for the The Resource Constrained Project Scheduling Problem with a flexible Project Structure and Consumption and Production of Resources
Tom van der Beek, Theresia van Essen, Jeroen Pruyn, Dimitris Souravlias

The Resource Constrained Project Scheduling Problem with a flexible Project Structure and Consumption and Production of Resources (RCPSP-PSCPR) is a scheduling problem where only a subset of all activities has to be executed. These activities are selected based on selection constraints and subsequently scheduled based on precedence and resource availability constraints. The RCPSP-PSCPR has applications in various real life projects, such as shipbuilding, housing construction or aircraft flight preparation. We present a procedure that generates cutting planes to strengthen the linear programming relaxation of the problem. Furthermore, we present two metaheuristic algorithms to handle larger instances. The performance of these algorithms is evaluated over two sets of test data. One set is generated for this research to capture all generalized aspects of the problem and one set is taken from literature for comparison purposes.

2 - Embedding decision-maker's preferences in the multi-objective Tabu search method for scheduling problems
Madani Bezoui, Alexandru Olteanu, Marc Sevaux

The integration of the decision maker's preferences in the optimization process of a multi-objective problem is a currently prominent research topic. In this work, we consider the scheduling problem of a flexible shop with multiple objectives, where the makespan, the total machining time and the maximum workload all have to be minimized. We assume that the decision maker can express multiple aspiration levels for each of the three objectives, as well as additional information that allows us to construct a preference model. This model corresponds to a SRMP (Simple Ranking using Multiple Profiles) model which we propose to integrate in a new Tabu search based approach. The SRMP model serves to order the neighboring solutions and thus help in implementing the descent phase, while the aspiration levels are also used to filter out neighboring solutions without needing to decode them beforehand. The proposal is compared to a state-of-the-art Tabu search algorithm on benchmark instances. Preliminary results show that our approach is quicker to find better solutions from the perspective of the decision maker.

3 - Exact solution of the two-machine flow shop problem with three operations
Federico Della Croce, Fabio Salassa, Vincent T'kindt

We consider a two-machine flow shop problem where each job j has three operations: the first operation must be processed on the first machine, the third operation must be processed on the second machine and the second operation can be processed either on the first machine immediately after the first operation or on the second machine immediately before the third operation. The goal is to minimize the makespan. This problem is known to be NP-Hard. We explore the strong links between this problem and another two-machine flow shop problem with common due date and jobs selection. Correspondingly we adapt to the considered problem the constraint generation approach already successfully applied to the latter problem. Computational testing indicates that proposed approach manages to solve to optimality in limited CPU time instances with up 40000 jobs in size.

4 - Selecting directed cycles: a polyhedral study
Marie Baratto, Yves Crama

The following "selection problem" is motivated by an application to kidney exchange problems. For a digraph G, a selection is a subset of arcs of G forming a union of directed cycles. When the arcs are weighted, the Maximum Weighted Selection (MWS) problem consists in finding a selection of maximum total weight. We prove that MWS is strongly NP-hard. Next, we focus on the selection problem associated with a complete digraph. We provide three complete ILP formulations of the problem: a "natural" one, featuring an exponential number of constraints which can be separated in polynomial time, and two extended compact ones. We investigate the relative strength of these formulations. We next concentrate on the natural formulation and on the description of the associated selection polytope. We prove that it is full-dimensional, and that all the inequalities used in the IP formulation are facet-defining. Furthermore, we describe three new classes of facet-defining inequalities. Then, we numerically test the proposed ILP formulation of MWS. Despite the theoretical complexity of the problem, the ILP formulation is very quickly solved for many random instances. We also study the problem when we include an additional constraint on the cardinality of a selection. Most of the results proved for the original case remain valid, but numerical tests show that the ILP formulation of the constrained variant is harder to solve.

■ TB-36

Tuesday, 10:30-12:00 - Virtual Room 36

Asset Pricing and Portfolio management

Stream: Risk management in Finance
Invited session
Chair: *Sergio Ortobelli*

1 - Skewed frontiers, inference, and international diversification
Somayyeh Lotfi, Stathis Paparoditis, Stavros A. Zenios

We consider a novel reward ratio maximization of mean-to Conditional Value-at-Risk (MTC) portfolio selection model to capture the skewness in the distribution of the returns, and develop a statistical inference test for testing the difference of MTC ratios across different strategies. We test the model on the international portfolio selection problem on a set of 22 developed and 20 emerging markets over 1999-2019 to study the impact of market frictions such as short-selling restrictions and transaction cost on the diversification benefit of the emerging market. Contrary to De Roon et al. (JF, 56(2):721-742, 2001), we find that diversification benefits in emerging market persist when the short-sales restriction is imposed. Moreover, considering the most recent data on transaction costs on developed market indices, we show that sophisticated investors that optimize the transaction costs have diversification benefit in the emerging market for transaction cost up to and including 0.5% which are in line with recent transaction cost data in emerging markets. Furthermore, consistent with previous literature, we find that long-term investors are better off with all diversification strategies over the index. Robustness tests using Japan and Eurozone as the home country and when currency-hedged returns are used confirm the main findings.

2 - Extreme Risk Quantification for High-Frequency Assets Based on Their Inherent Degree of Impulsiveness
George Tzagkarakis, Frantz Maurer

Extreme risk quantification for illiquid high-frequency (HF) assets, whose reported prices suffer from multiple biases, is a highly challenging task in financial practice. Illiquidity raises market microstructure frictions, e.g. bid-ask bounce and non-synchronous trading, which manifest themselves as returns autocorrelation, thus contaminating the data. Another problem is that autocorrelation and illiquidity do not occur at the same frequency. As a result, existing methods investigating diversification performance of portfolios including illiquid HF assets typically under-estimate the true risk, yielding biased results in favor of illiquid assets. To address these problems, we propose a novel extreme risk quantification method tailored to investments in illiquid HF assets. In particular, HF returns are first decomposed at multiple time-scales to capture both autocorrelation and illiquidity at distinct frequencies. Then, the inherent impulsiveness of an optimal subset of multiscale returns, that are most relevant to the trading horizon, is modelled via alpha-stable distributions. In contrast to conventional risk measures, primarily relying on second-order statistics, we employ fractional lower-order moments (FLOMs) to calculate scale-by-scale extreme quantiles. Finally, our FLOM-based extreme risk measure is defined as a nonlinear combination of distinct alpha-stable quantiles. Experiments demonstrate increased robustness of our method in efficiently controlling extreme risk.

3 - ETS, Emissions and the Energy-Mix Problem
Paolo Falbo, Cristian Pelizzari, Giorgio Rizzini

In this paper, we investigate the impact of ETS on the emissions and the energy-mix through a bilevel model where a policymaker interacts with an oligopolistic electricity market over a finite time horizon. At the upper level, the policymaker aims at maximizing a welfare function deciding the optimal number of allowances to be distributed to the electricity market. At the lower level, the electricity market, represented by two large companies, decide the optimal long-term capacity expansion between conventional and non-conventional technologies. The uncertainty is modelled through scenarios, obtained using Markov chain bootstrapping, made of coal and gas prices and electricity demand. We solve the problem considering a large set of efficient equilibrium solution between the two electricity producers. We provide a model calibration through real data and a detailed comparative statics.

4 - Robust portfolio dominance for different investors' preferences
Sergio Ortobelli, Tommaso Lando

In this paper, we propose a methodology to obtain optimal portfolios that stochastically dominates in a robust sense a benchmark with respect to different stochastic orderings. Firstly, we recall some recently proposed orderings that classify the optimal choices for different non satiable investors' categories. Secondly, we discuss on the selection models of optimal portfolios that stochastically dominate a given benchmark taking into account a significative distance according to stochastic dominance tests. Finally, we propose an ex-post empirical analysis where we evaluate the proposed models for different investors' preferences.

■ TB-38

Tuesday, 10:30-12:00 - Virtual Room 38

Vaccine Supply Chains

Stream: ORAHS: OR in Health and Healthcare
Invited session
Chair: *Katarzyna Gdowska*

1 - Risk Assessment for Vaccine Supply Chain using MCDM and Fuzzy Rule Base Approach
Mahima Gupta, Vijaya Dixit

In today's pandemic hit world, supply of vaccine plays a pivotal role in overcoming the challenges. However, vaccine supply chain (VSC) network is prone to uncertainties and complexities. The supply chain complexity increases multi-fold in the vaccine supply chain due to the unique characteristics of the product involved in the process. Multiple factors such as the availability requirements to control the spread, storage and transportation needs to minimize the wastage, and many policy decisions to ensure equity in the process etc. bring about many questions on the design, implementation and operation of its supply chain. This paper aims to develop a novel Multi-criteria decision making model to assess the risk factors of vaccine supply chains. The proposed model maps the risk assessment on three dimensions i.e. likelihood, visibility and impact on supply chain performance objectives namely economical, technological and value-based. Since the decision maker find it easier to express their assessment in day to day terms, their assessments in five different dimensions are assessed in linguistic terms. The interrelationships among different dimensions and the consequent significance of the risk is expressed as if-then rules. These rules are used to quantify the significance of the risk using fuzzy rule base system. The findings would benefit all the players in the VSC to assess the risks and take remedial measures to mitigate the supply chain risks in the VSC.

2 - A Hybrid Contract to Coordinate Rotavirus Vaccine Supply Chain in India
Dheeraj Chandra, Vipin B

Rotavirus affects millions of children every year in developing and developed nations. According to the world health organization estimates of 2013, approximately 0.2 million children under five years died of rotavirus globally, of which 22% of children are from India. Through discussion of experts, we identify that the existing rotavirus vaccine procurement system of universal immunization program (UIP) India which neglects the uncertain nature of demand and considers only stochastic production yield. We analyze the traditional wholesale price (WSP) contract for the existing situation and report that the WSP contract cannot coordinate the vaccine supply chain (VSC). We propose a hybrid contract for UIP India by considering demand and production yield uncertainty to coordinate the VSC. We validate our findings with a case study reference in the Indian setting. Our findings will be beneficial to the policymakers of UIP India and other nation's child immunization programs to optimize rotavirus VSC performance.

3 - A New Conceptual System Dynamics Based Model For Covid-19 Vaccine Supply Chain
Burcin Cakir Erdener, Ayyuce Aydemir-Karadag, Nasibeh Azadeh Fard, Fatma Pakdil, Neset Hikmet

In the COVID-19 pandemic that all countries are struggling with, the countries' most potent weapon is the vaccine. While combating the epidemic, the most critical factor is implementing a fast and fair distribution of the vaccine to the maximum number of people. Therefore, the vaccine supply chain must be effectively planned at all phases, from the vaccine production to the end-user's vaccination. This study presents a conceptual system dynamics model for the vaccine's supply chain and determines the key performance indicators and various objective functions for each phase in the chain. We further propose a mathematical model which appropriately optimizes the key decisions of the supply and distribution planning. The proposed model reveals the interactions of decisions among phases and illustrates the relationships among the system's decision variables.

4 - Optimizing a global vaccination plan
Radosław Kapłan, Piotr Łebkowski, Katarzyna Gdowska, Roger Książek

Although COVID-19 vaccines have been developed, their distribution is still a challenge for the decision-making units, both at the international level (e.g. the European Union) as well as federal or national ones. The objective is to distribute vaccines, so that the transmission of the virus can be reduced, and the pandemic can be over. However, the vaccine supply is limited with the capacity of the producers. In this paper a problem of vaccine distribution is presented. The objective is to supply regions with available dosed of different types of COVID-19 vaccine, so that the expected value of the total number of people who can get infected is minimized. The regions can differ one from another, so different numbers of vaccines should be assigned to each of them in each planning period. The problem is solved using MIP model optimizing the global vaccination plan. Results of computational experiments are presented and discussed.

■ TB-39

Tuesday, 10:30-12:00 - Virtual Room 39

Routing under uncertainty II

Stream: Routing, Logistics, Location and Freight Transportation
Invited session
Chair: *Natasja Sluijk*

1 - A three-stage model to support capacity decisions in intermodal transport under uncertainty
Thibault Delbart, Yves Molenbruch, Kris Braekers, An Caris

Intermodal transport is the transport of freight with multiple modes whereby freight remains in the same loading unit. The combination of road transport with other modes is potentially more sustainable than unimodal road transport for long-haul freight shipping. Transport networks are subjected to uncertainty and an important hindrance to the modal shift is the lower flexibility of other transport modes compared to trucks following uncertain events. This work proposes a decision support model to assist intermodal transport planning under uncertainty and presents experimental results from small artificial instances. The proposed stochastic optimization model supports capacity decisions on railway links. Included uncertainties are stochastic demand, available train slots that can be booked at each stage and variations between actual capacity and booked capacity. In the considered context, initial capacity decisions should be made before demand is known and updated later on when more information becomes available. Our model differs from existing two-stage models for service network design by including a third stage, allowing to more accurately imitate real-life decision making.

2 - A Chance-Constrained Two-Echelon Vehicle Routing Problem with Stochastic Demands
Natasja Sluijk, Alexandre Florio, Joris Kinable, Nico Dellaert, Tom van Woensel

Two-echelon distribution systems are often considered in city logistics to maintain economies of scale and satisfy the emission zone requirements in the cities. In this work, we formulate the two-echelon vehicle routing problem with stochastic demands as a chance-constrained stochastic optimization problem, where the total demand of the customers in each second-echelon route should fit within the vehicle capacity with a high probability. We propose two efficient solution procedures based on column generation. Key to the efficiency of these procedures is the underlying labeling algorithm to generate new columns. We propose a novel labeling algorithm based on simultaneous construction of second-echelon routes and a labeling algorithm that builds second-echelon routes sequentially. To further enhance the performance of the solution procedure, we use statistical inference techniques to ensure that the chance constraints are met. We reduce the number of customer combinations for which the chance constraint needs to be verified by imposing feasibility bounds on the stochastic customer demands. With these bounds, the runtimes of the labeling algorithms are reduced significantly. Finally, we show the value of the stochastic formulation in terms of improved solution cost and guaranteed feasibility of second-echelon routes.

3 - The Vehicle Routing Problem with Availability Profiles
Markus Frank, Stefan Voigt, Pirmin Fontaine, Heinrich Kuhn

We address the failed-delivery problem in B2C parcel delivery by considering customer-individual availability profiles (APs) that consist of a set of time windows, each associated with a probability that the delivery is successful if conducted in the respective time window. To assess the benefit of APs for delivery tour planning, we formulate the vehicle routing problem with availability profiles (VRPAP) as a mixed integer program (MIP), including the tradeoff between transportation and failed-delivery costs. We provide analytical insights concerning the model's cost savings potential by determining lower and upper bounds. In order to solve larger instances we develop a novel hybrid adaptive large neighborhood search (HALNS) with problem-specific operators. We find new best-known solutions for related benchmark instances from the literature and conduct various experiments on self-generated instances. In a case study using real-world data, despite little information on the APs, we were able to reduce failed deliveries by approximately 12% and overall costs by 5%.

4 - The Two-Echelon Stochastic Multi-period Capacitated Location-Routing Problem
Imen Ben Mohamed, Walid Klibi, Ruslan Sadykov, François Vanderbeck

This paper tackles the two-echelon stochastic multi-period capacitated location-routing problem (2E-SM-CLRP). The network is partitioned into two capacitated distribution echelons: each echelon involves a specific location-assignment-transportation schema that must cope with the future demand. It aims to decide the number and location of warehousing platforms and distribution platforms, and on the capacity allocated from first echelon to second echelon platforms. In the second echelon, the goal is to construct vehicle routes that visit ship-to locations from operating distribution platforms under a stochastic and time-varying demand and varying costs. This problem is formulated as a two-stage stochastic program with integer recourse and solved by an exact logic-based Benders decomposition algorithm. In the proposed approach, the location and capacity decisions are taken by solving the Benders master problem. After these first-stage decisions are fixed, the resulting sub-problem is a capacitated vehicle-routing problem with capacitated multiple depots (CVRP-CMD) that is solved by a branch-cut-and-price algorithm. Two families of Benders cuts are proposed to cut off infeasible solutions and to help converging to the optimal solution of the 2E-SM-CLRP. Computational experiments show that instances of realistic size can be solved optimally within a reasonable time and provide relevant managerial insights on the impact of the stochastic and multi-period settings on the 2E-CLRP.

■ TB-40

Tuesday, 10:30-12:00 - Virtual Room 40

Integrated scheduling problems

Stream: Scheduling and Project Management
Invited session
Chair: *Jean-Charles Billaut*
Chair: *Lotte Berghman*

1 - Iterative Approach based on Constraint Programming for the RCPSP with Transportation
Marina Vinot, Philippe Lacomme, Eric Bourreau

Integrated problem with transportation and scheduling problems encompasses many constraints including for example the precedence and synchronization constraints between transportation operations and scheduling operations. Exact resolution based on linear formulation or heuristic based approaches expect difficulties in finding a simple feasible solution due to the large number of binary variables and big M required by the model.

The transportation problem in the RCPSP consists in the transportation of resources required by activities using a fleet of homogenous vehicle of limited capacity. Computation of a flow permits to have the pickup activity, the delivery activity with the quantity and the transportation problem is then a PDP problem that must be solved. The optimal RCPSP flow does not lead to an optimal solution of the RCPSP with transportation and an iterative search procedure is required. We introduced a decomposition-based approach with a constraint programming modeling and the experiments have been achieved with Choco Solver.

Our research is now directed on the RCPSP with transportation considering n-to-n PDP that required computation of transportation solution where the vehicles can achieve trip with several consecutive pickup operations.

2 - An Integrated Approach for the Transit-Time Sensitive Liner Ship Scheduling and Container Routing Problem
Aleyna Gürsoy, Semih Yalçındağ, İrem Sultan Hastürk

As a result of globalization, decision support systems that ensure the right decisions are made at operational, tactical, and strategic levels are crucial in the field of maritime transportation. Since most of the transportation demand is met via seaways, maritime transportation plays an important role in global commerce. In this context, Liner Ship Scheduling Problem (LSSP) and Container Routing Problem (CRP) are two main problems that have been studied in the operations research literature in the recent years. Faced by long transit times, customers seek services that offer reasonable delivery times as they choose a maritime carrier. Therefore, maritime companies should design their schedules to deliver customer demand as quickly as possible to remain competitive in the global market. In the literature, there is only one study that addresses transit time-sensitive demand at the operational level within CRP. In this research, we account for transit time-sensitive demand at both tactical and operational levels through an integrated approach. This approach combines the LSSP and CRP (LSSCRP) to improve the total profit by designing the best liner services and routes customer containers through the resulting network. This approach allows us to obtain a solution in a reasonable time and increases the quality of the service offered to the customer, thus contributing to the profitability and competitiveness of maritime companies in the global market.

3 - An integrated model for routing trains and scheduling maintenances in Italian Railways
Paolo Dell'Olmo, Lavinia Amorosi, Gianluca Giacco

This talk deals with a problem receiving increasing attention for its economic implications in the railway companies and in the safety of travelers. The growing demand for high-speed trains and the competition with other operators pushes companies to increase rail transport services to better meet the demand with obvious implications on the companies' profit. However, the high-speed trains have to undergo special maintenance services, with predetermined constraints ill-structured and difficult to represent mathematically. In addition, the maintenance service is highly specialized and can only run on specific platforms in the stations of destination and is subject to a more articulated process. This makes models existing in the literature not adequate to represent these new problems. In particular, formulations of the problem of routing of trains integrated with the one of the scheduling maintenances do not exist, even if, indeed, the two problems affect each other and formulations of the two separate parts lead to suboptimal solutions of the overall problem. In the talk a new integrated mixed integer mathematical formulation is presented, and computational results are discussed

4 - The use of order forecasts in the online integrated order batching, picker routing and picker scheduling problem
Ruben D'Haen, Kris Braekers, Katrien Ramaekers

Companies need efficient order picking operations to offer a competitive service level at a low cost. These order picking operations consist of multiple interrelated planning problems: order batching, picker routing and picker scheduling. Although these problems are usually solved individually, solving them in an integrated way leads to improved solutions. This integrated batching, routing and sequencing problem (IBRSP) has been studied in a static setting. However, in practice, new orders arrive throughout the day and may need to be picked very quickly to fulfil urgent customer requests. Therefore, we propose a new variant of this problem, the online IBRSP, and a meta-heuristic algorithm to solve it. Every time an order picker finishes his previous task and requests a new picklist, we check whether new orders arrived. If new order arrivals occurred since the last optimization, a new schedule is constructed by integrating these new orders in the previous schedule. Because urgent orders may arrive during the picking operations, it may be necessary to reserve some time for these dynamically arriving orders from the beginning of the planning horizon to avoid tardiness. Therefore, we study how much time should be allocated to these forecasted orders in order to minimize tardiness while keeping the order picking cost under control.

■ TB-41

Tuesday, 10:30-12:00 - Virtual Room 41

Integrating planning problems

Stream: Timetabling and public transport
Invited session
Chair: *Richard Lusby*

1 - Solution Approaches for Integrated Vehicle and Crew Scheduling with Electric Buses
Shyam Sundar Govindaraja Perumal, Twan Dollevoet, Dennis Huisman, Richard Lusby, Jesper Larsen, Morten Riis

The use of electric buses is expected to rise due to its environmental benefits. However, electric vehicles are less flexible than conventional diesel buses due to their limited driving range and longer recharging times. Therefore, scheduling electric vehicles adds further operational difficulties. Additionally, various labor regulations challenge public transport companies to find a cost-efficient crew schedule. Vehicle and crew scheduling problems essentially define the cost of operations. In practice, these two problems are often solved sequentially. We introduce the integrated electric vehicle and crew scheduling problem (E-VCSP). Given a set of timetabled trips and recharging stations, the E-VCSP is concerned with finding vehicle and crew schedules that cover the timetabled trips and satisfy operational constraints, such as limited driving range of electric vehicles and labor regulations for the crew while minimizing total operational cost. An adaptive large neighborhood search that utilizes branch-and-price heuristics is proposed to tackle the E-VCSP. The proposed method is tested on real-life instances from public transport companies in Denmark and Sweden that contain up to 1,109 trips. The heuristic provides evidence of improving efficiency of transport systems when the electric vehicle and crew scheduling aspects are considered simultaneously. By comparing to the traditional sequential approach, the heuristic finds improvements in the range of 1.17-4.37% on average.

2 - Simultaneously re-optimizing timetables and platform schedules under planned track maintenance for a high-speed railway network
Qin Zhang, Richard Lusby

Train timetabling and train platforming are problems of crucial importance when scheduling high-speed trains. Often, these problems are solved separately and in sequence. It is also not uncommon for the problems to be further decomposed by direction since the use of tracks is usually direction specific in a high-speed network. In this paper, we consider the optimization problem of integrating re-timetabling and re-routing decisions within station areas for multiple stations when scheduled maintenance renders the existing, optimized schedules infeasible. We model the underlying problems using a space-time network on a mesoscopic level and propose a 0-1 binary integer programming model that can simultaneously modify the timings and routes of trains from different directions. Two different solution approaches are described. The first is a commonly used Lagrangian Relaxation approach, while the second utilizes the Alternating Direction Method of Multipliers concept. A comparison of the two approaches on instances provided by the Chinese high-speed railway indicates that the ADMM-based approach provides tighter upper bounds and typically requires fewer iterations than the Lagrangian Relaxation approach. Furthermore, the results show that a flexible track utilization policy provides better timetables, with fewer cancellations and less total delay, than a fixed, dedicated direction, track policy.

3 - Optimal battery replenishment and vehicle-charger assignment for dynamic electric demand responsive transport service
Tai-yu Ma

Electrifying electric vehicle fleet for demand-responsive transport (DRT) service needs to efficiently manage the daily charging operation to minimize charging waiting times and cost under stochastic customer demand. Given capacitated charging facilities and varying charging prices, the issue of determining where, when, and how much to charge for each vehicle is a challenging issue for successful deployment of e-fleet. In this study, a new two-stage solution approach is proposed to handle dynamic vehicle charging scheduling to minimize the costs of daily charging operations of the DRT service. A new battery replenishment model is proposed to obtain a day-ahead charging schedule for each vehicle based on the historical driving patterns of vehicles. Then an online vehicle-charger assignment model is developed to determine where to charge by considering queuing delays at the level of chargers. An efficient Lagrangian relaxation algorithm is proposed to solve the large-scale vehicle-charger assignment problem with small optimality gaps. The approach is applied to a realistic dynamic dial-a-ride service case study in Luxembourg and compared with the nearest charging station charging policy and first-come-first-served minimum charging delay policy under different charging infrastructure scenarios. The computational results show that the approach can achieve significant savings for the operator in terms of charging waiting times, charging times, and charged energy costs.

4 - Autonomous On-Demand Transit Services Over Existing Guideways
Mor Kaspi, Omer Karny

Technological advances in vehicle autonomy, vehicle connectivity and vehicle electrification are expected to revolutionize urban mobility. However, due to many barriers, a significant adoption of fully autonomous vehicles is only projected to occur in two to three decades. Large scale deployments of novel mobility services provided using autonomous vehicles could potentially be implemented in the near future in controlled environments. This study examines the potential of transforming existing guideway based public transportation systems (tram, light-rail, BRT) to on-demand point to point services by utilizing current technological capabilities. In particular, the objective it to reveal the characteristics of existing systems that have high potential to be successfully transformed to flexible on-demand services. For this purpose, an approximate model and a simulation model that represent the dynamics of the service are developed. The approximate model is based on the Israeli Queue model which allows accurately measuring the waiting times of the passengers under ridesharing policies. The simulation model replicates in more details the operations of the proposed service while relaxing several simplifying assumptions made in the approximate model. Numerical results obtained for case studies derived from several public transit systems around the world, confirm that the proposed service can reduce by up to 50% the average waiting time, as compared to existing services.

■ TB-43

Tuesday, 10:30-12:00 - Virtual Room 43

Circularity in Supply Chains

Stream: Environmental Sustainability in Supply Chains
Invited session
Chair: *Gerald Reiner*

1 - circular economy and humanitarian food supply chain management in Spain during COVID19: a case study
Maria Alvarez, José Silva

The circular economy approach has revealed itself in the COVID19 pandemic as a useful tool in assisting companies with social purposes in the provision of their humanitarian functions and with the reinforcing of the food supply chain management function particularly. This communication brings into the light an ad-hoc case study that has been developed from the first-hand experience provided by COMMANITAS, a real company located in Algeciras, Campo de Gibraltar, Spain, with the main purpose to help Operations Management students to get closer to the reality of the impact of Covid-19 on the contents of the discipline. At the same time, they are illustrated on the possible and adequate coexistence of the ethical and humanitarian components of Operations Management and the reinforcement of business resilience while continuing to meet the SDGs and improving the business EHS strategy.

2 - A multi-objective solution approach to assess the trade-off between packaging, food waste and environmental impact in grocery retailing
Adhurim Imeri, Christian Fikar, Gerald Reiner

Grocery retailing can either be a trigger or a diminisher of solutions towards reaching the supply-demand equilibrium for perishable products. The mismatch between supply and demand influences the generation of food waste. Within this context, various research studies identifies that a trade-off between packaging, environmental emissions and food waste exists. Such a trade-off is affected by operations beyond the retail shop floor which can be typologized in product quality influencers such as temperature during distribution, managerial behaviour, logistics operations, replenishment policies and return logistics. This work combines a multiobjective metaheuristic and a hybrid simulation to investigate the relation of the corresponding trade-offs. Based on the operational typology, different scenarios are analysed in order to assess the sensitiveness in such trade-offs. The developed tool provides managerial decision support, particularly for assessing novel packaging technologies that make it possible to obtain real-time information of the quantity and quality of the product being traced.

3 - Reducing the bullwhip effect and plastic waste through incentivization by blockchain technology - The case of the plastic bottle supply chain
Gerald Reiner, Maximilian Kunovjanek, Christian Wankmüller, Romana Polt, Johannes Pulsfort

This research study investigates the impact of blockchain technology (BT) on plastics supply chains (SC) to reduce plastic bottle waste along relevant SC processes (e.g. transport, storage, return). Aside from various causes, the bullwhip effect (BWE) in global SCs represents a major reason for the tremendously increased plastic pollution worldwide. This gradual increase of variability related cost drivers (e.g. inventories) upstream in a SC mainly stems from information distortion and lacking visibility between SC partners. BT seems to be a breakthrough for addressing those inefficiencies and for handling information distortion as compared to common electronic data interchange solutions. In the context of plastics SCs, the technology promises to enhance plastic flow visibility and SC data quality (e.g. point-of-sale) as well as data security. The tracking and tracing functionality of BT supports the collection of real-time information on plastic bottles (e.g. location) and potentially enables an incentive system to obtain higher collection and recycling rates. When combined with innovative SC policies a more risk hedging plastic value chain in terms of virgin raw material prices can be created, which in turn increases SC efficiency. The study proposes a system dynamics model that explores the key characteristics of BT in the context of the plastics life cycle while considering the BWE.

■ TB-44

Tuesday, 10:30-12:00 - Virtual Room 44

X-Ray of the Perfect Practitioner

Stream: Practice of OR (Making an Impact)
Invited session
Chair: *Theodore Athanasopoulos*

1 - The Perfect Practitioner
Theodore Athanasopoulos, John Poppelaars, Arjen Rietveld, Georgios Dikas

The focus of the session is to investigate the skills (or requirements), qualities that a "good" OR practitioner has. We consider as an 'OR practitioner' somebody who is working as an OR, or analytics or data science consultant (industry, consulting), without direct ties to academia. The session will include talks / discussion from experienced OR professionals with the aim to answer questions as, what are the main characteristics and the strengths of an OR practitioner, how an OR candidate can improve certain qualities in order to make larger impact, etc. The round table discussion will explore topics such as what are the talents, abilities they are looking at their teams, and invites audience question and comment to find out what makes the perfect practitioner.

■ TB-45

Tuesday, 10:30-12:00 - Virtual Room 45

Application of OR for Embedded Systems

Stream: Specific Applications of OR (contributed)
Contributed session
Chair: *Lilia Zaourar*
Chair: *Lucía Bautista Bárcena*

1 - Circuit partitioning with path delay-based minimization
Julien Rodriguez, François Galea, Frnaçois Pellegrini, Lilia Zaourar

Hypergraph partitioning has been used in several areas including circuit partitioning for VLSI design since the 1970s. The process of evaluating and verifying a System on a Chip (SoC) involves using Field-Programmable-Gate-Arrays (FPGAs). Nowadays, the increasing size of Integer Circuits (IC) requires partitioning them in several subcircuits. Each one is then mapped onto a multi-FPGA platform while respecting some constraints. This work focuses on the minimization of the maximum path delay.

There are several tools that allow hypergraph partitioning, like hMETIS, PaToH and KaHyPar. These solvers minimize a "min-cut" objective function based on individual penalties for each of the cut hyperedges. The minimization problems for "min-cut" are NP-hard.

Even though this function tries to minimize the number of hyperedges (nets) between parts (vertex set), it does not solve the path delay minimization. There exist some previous works that deal with the timing constraint with good results (40 % delay improvement) but the main objective function remains min-cut.

In this paper, we devise a mathematical model for the problem of IC partitioning with path-delay-based minimization that takes into account various constraints. We propose a way to derive the classical multilevel approach for graph/hypergraph min-cut methods to adapt it to our specific problem.

2 - Deterioration of a system with Cox arrival times.
Lucía Bautista Bárcena, Inmaculada Torres Castro, Luis Landesa Porras

The use of multiple degradation processes in the modeling of a system deterioration has been increasing in recent times. Electronic devices and other complex machines are often subject to multiple degradation processes since their components can deteriorate in different ways.

There are two approaches to explain the deterioration mechanism of a system. It can be considered that all the processes start to deteriorate the system at the same time. On the other hand, the processes could start at different random times. It is common to use the non homogeneous Poisson process to describe the arrival times of the degradation process in the system.

In this work, we will considerate two different stochastic processes: the initial processes (arrivals) and the growth processes. We can keep in mind the pitting corrosion process as an example: the pits start at random times and the growth is modelled by another stochastic process. A Cox process is used to model the arrival times of the degradation processes to the system. It is a generalization of the non-homogeneous Poisson process, with the main difference that the intensity of the arrivals is itself a stochastic process. Using the properties of this type of processes, the system reliability is studied.

3 - Mathematical modelling of Logic Locking against the insertion of Hardware Trojan in an Integrated Circuit
Jonathan Fontaine, Lilia Zaourar, Roselyne Chotin

Nowadays, the increasing complexity of electronic devices has led to increase their cost. Therefore, several external agents ensure a part of the production of an Integrated Circuit (IC). A new threat has emerged from those companies. Checking that an IC works as specified by the designer and is not doing secret tasks is very difficult. In fact, it is possible to add electronic component to a malicious purpose, named Hardware Trojan (HT). This is a major security issue, especially for IC used in critical fields as transportation, health or military. It can be information leakage, material deterioration or denial of service. A solution to avoid that is to use Logic Locking. This method use a numeric key to lock the IC, which is only known from the designer. The aim is to obfuscate the logic function of the IC for untrusted party. Its purpose is to increase the security of the IC while limiting the impact on power consumption, critical path and area. The aim of this work is to model logic locking as an optimization problem. We represent the IC by a graph and express the set of constraints with a non-linear model. We first solved it exactly by linearization for small instances and we implemented a heuristic for larger ones. It compute for each pair of vertices the notion of pairwise secure. Then get all the maximum cliques. Finally, select the largest cliques, until reaching fixed keychain limit. We will present the numerical results and the prospects for improvement.

■ TB-46

Tuesday, 10:30-12:00 - Virtual Room 46

Transportation in supply chains

Stream: Production and logistics and revenue management (contributed)
Contributed session
Chair: *Philippe Lacomme*

1 - Secondary full truck load marketplace in a physical internet environment
Claudio Szwarcfiter, Yossi Bukchin, Tal Raviv

We consider a full truck load (FTL) transportation marketplace consisting of a demand for shipments of standardized containers between a large set of terminals and a supply of occasional truck drivers who are willing to sell the service of their truck for transferring the containers between the terminals A mediator sells transportation services between the terminals by acquiring services from the drivers and providing it to the shippers. A load can be transferred from its origin to its destination in several legs where the terminals are used as intermediate storage. This way, it is possible to provide efficient transportation between all the terminals in the network even when the supply does not match all the required origin-destination pairs. The mediator posts periodically the shipping prices to the shippers market and the transportation payments to the drivers, and later on, at the operational level, assigns containers to drivers. If the mediator is a profit maximizing firm, its objective is to maximize its revenue from the shippers net of its payments paid to the drivers and the compensations for delays. If the mediator is an authority that wishes to maximize the environmental and traffic benefits of economizing the FTL industry, its goal is to maximize the volume of the transportation services that it can provide.

2 - Transportation, As a Complementary Element of Logistics: Sectoral Evaluation of Maritime Shipping Industry
Burçin Özdamar, Adem Tüzemen

Due to global COVID-19 pandemic has strictly affected the ongoing processes under the umbrella of logistics, many areas have been witnessed across several last-minute issues to be solved. Herein, maritime transportation faced with the unexpected changes and events during the operations. This study aims to elaborate the current situation of maritime transportation, one of the backbones of logistics, by focusing on shipping industry with the following research questions: RQ 1) What are the best practices in maritime shipping industry? RQ 2) What is the role of maritime transportation as a complementary element of logistics? While conducting this study, forecasting methods will be used for estimating the current model of maritime transportation, focusing on shipping industry by analyzing best practices in the extant literature and conducting secondary statistical data analysis . This research follows steps to detect the need of potential improvements in the industrial point of view. Then, periodic calculations regarding the maritime shipping industry will be compared by forecast evaluation criteria After getting preliminary results from the ongoing research, the results will be analyzed and evaluated through simulation method. Findings of this study will reveal the potential of maritime transportation (e.g. regarding capabilities, crisis management abilities and precautions for supply chain disruptions) to develop effective future strategies.

3 - Synchromodal pricing strategies from a network flow perspective
Jasper Paesen, Lotte Verdonck, Christof Defryn, An Caris, Stan Van Hoesel

In the transport industry, long term contracts between shippers and logistics service providers are common. These contracts typically contain commitments related to volume, lead time and price. As these contracts run over a longer period (e.g., a year), these commitments are made long before the execution of the transport service itself.

Synchromodal transportation, however, is founded on the idea of having the flexibility to change decisions with respect to, e.g., route and transport mode in real time, which leads to challenges to make the typical commitments long in advance.

In this research, we study pricing strategies from a network flow perspective. More specifically, we focus on the impact of this mix of long-term commitments (contracts) and ad-hoc shipping on network planning and pricing.

4 - On the Truck Driver Scheduling Problem: A Constraint Programming based approach
Philippe Lacomme, Eric Bourreau, Katyanne Farias, Thierry Garaix, Ivan Pena, Diego Martino

Rules on driving, working and breaks scheduling are crucial to enhance road safety and to respect drivers' work conditions. Thus, adapting the vehicle routes that are commonly defined in routing optimization problems to integrate these rules leads us to the Truck Drive Scheduling Problem (TDSP) which purpose is to guarantee their compliance according to the European Union regulations. In this respect, we present the first Constraint Programming (CP) based approach for the TDSP which integrates rules regarding the driving, service, working time and breaks duration considering a one-week horizon time. Driving time concerns only the transportation time from one customer to another, service time as transportation and processing duration and working time encompass all activities within a day of work. Breaks between activities and night breaks must meet the law requirements. Therefore, the main idea of our CP-based algorithm is to schedule the arrival, starting, finishing and departure dates and define the breaks duration before and/or after the activities considering the EC regulation 561/2006 so that the completion time is minimized. Tests were performed in a set of 29 instances and results show that the majority is solved into optimality in less than one second and others present at most a 1% gap, which validates our algorithm effectiveness.

■ TB-47
Tuesday, 10:30-12:00 - Virtual Room 47

OR and Marketing Systems

Stream: OR in Marketing
Invited session
Chair: *Ioannis Issaris*

1 - Analyzing customer satisfaction of short food supply chains
Antonios Tiganis, Evangelos Grigoroudis, George Baourakis

The importance of short food supply chains is justified by the European Union policies and the FAO guidelines. Previous research has focused on consumers' motives for purchasing food from local food systems, such as environmental awareness, societal concerns, quality preferences, and nutritional concerns. This research approaches food consumption through short networks from a customer satisfaction perspective, based on the Marketing Mix theory. The main aim is to estimate the effect of the 7Ps of the Marketing Mix (Product, Placement, Promotion, Pricing, Producers, Process of Sales, and Purchase Environment) on overall customer satisfaction. Sampling took place from December 2020 to January 2021, and the final sample included 765 respondents. The data have been analyzed using the Multicriteria Satisfaction Analysis (MUSA) method. The most important criteria are the sales process and the producers, followed by the placement and pricing methods, while the least important criteria are the methods of promotion, the product, and the purchase environment. The results confirm the role of services and trust, as indicated in the Marketing Mix and the literature on Short Food Supply Chains, respectively. On the other hand, the role of product attributes that is so much discussed in the relevant literature seems weaker compared to the other elements of Marketing Mix.

2 - Antecedents and Outcomes of Inter-Customer Social Support in Service Encounters
Vassiliki Grougiou, Ilias Kapoutsis

The emotional similarity hypothesis (Schachter 1959) postulates that individuals who encounter stressful life situations are more likely to experience an increased desire to affiliate with others, possibly facing similar problems. These interactions intend to foster feelings of understanding, safety, and pleasure (Doorn et al. 2010). According to tension reduction theories of human motivation (McGuire 1974), the social dimensions of service interactions can improve stress-burdened customers' affective state. Most studies have linked stressful life situations with materialism and compulsive consumptions (Richins and Chaplin 2015), ignoring the relationship between inter-customer social support in service settings and critical life events. Paradoxically, while customer characteristics have often been suggested to affect inter-customer social support, they still have not been thoroughly investigated (Grougiou and Pettigrew 2011). This paper examines the roles of adverse life events, gender, and age on inter-customer social support and the reciprocity effect of the latter on several post-consumption behaviors. Based on a sample of 867 respondents drawn from diverse service settings, we find that females, seniors, and those facing critical life events are more inclined to seek inter-customer social support. When customers receive inter-customer social support, they reciprocate by engaging in customer citizenship and favorable post-consumption behaviors.

3 - Development of a Multi-Criteria Decision Support System for Markets' and Life Cycle Simulation, based on Behavior Analysis
Foteini Kalafati, Efstathios Gerampinis, Dimitrios Chelioudakis, Garyfallia Matsatsini, Nikolaos Matsatsinis

This work presents a new multi-criteria methodology for market and product life cycle simulation in a competitive market. The proposed methodology extends the MARKEX system methodology for the development of new products and for the simulation of the product life cycle. Based on the results of the criteria analyzes, using MARKEX methodology, and the satisfaction analysis of the product in question, using the MUSA method, scenarios of improvement of the market shares of the product under study and extension of its life cycle are applied. A web-based Multicriteria Decision Support System was developed to implement this methodology. Finally, the results of its application in the data of a market research are presented.

4 - Machine Learning for business: From Clusters to Action
Ioannis Issaris

A well-structured database, optimized processes and experienced personnel do not always ensure that the most appropriate actions are taken to achieve a company's goals. This becomes even more noticeable especially when these actions are important to be done quickly. By introducing Machine Learning tools into a modern CRM we can act at the right time on potential customers who are more likely to buy and whose profile is the most attractive to us.

■ TB-48

Tuesday, 10:30-12:00 - Virtual Room 48

Optimal Control in Environmental and Resource Economics

Stream: Optimal Control Theory and Applications
Invited session
Chair: *Thorsten Upmann*

1 - Investment in Cleaner Technologies in a Transboundary Pollution Dynamic Game. A Numerical Investigation
Guiomar Martin-Herran, Javier de Frutos, Paula M. López Pérez

Within a non-cooperative transboundary pollution dynamic game, we study the strategic impact of a region's investment in the adoption of a cleaner technology, as embodied by a reduction in the emission per output ratio, on the equilibrium outcomes and regions' welfare. The ratio of emissions to output is endogenous and is a decreasing function of the level of the stock of clean technology. Each region can invest in a clean technology in addition to its control of emissions. Clean technology is assumed to be public knowledge so that both regions benefit from the investment in clean technology of an individual region. Pollution damage is modelled as a strictly convex function in the pollution stock. We analyze the feedback equilibrium of the non-cooperative game between two regions played over an infinite horizon. The formulation of the transboundary pollution dynamic game does not fit any special structure of analytically tractable games such as linear-state or linear-quadratic differential games. We develop numerical methods to characterize the feedback equilibrium of the non-cooperative game between two regions. The equilibrium trajectories of the stock of pollution and stock of clean technology as well the regions' welfare are compared under different scenarios.

2 - A Dynamic Theory of Spatial Externalities
Salvatore Federico, Fausto Gozzi, Giorgio Fabbri, Boucekkine Raouf

This work targets the class of spatiotemporal problems with free riding under natural (pollution, epidemics...etc) diffusion and spatial externalities. Such a class brings to study a family of differential games in continuous time and space. In the fundamen- tal pollution free riding problem we develop a strategy to solve completely the associated game contributing to the associated debate on environmental federalism. We depart from the preexisting literature in several respects. First, instead of assuming ad hoc pollution diffusion schemes across space, we consider a realistic spatiotemporal law of motion for pollution (diffusion and advection). Second, we tackle spatiotemporal non-cooperative (and cooperative) differential games instead of static games in the related literature. Pre- cisely, we consider a circle partitioned into several states where a local authority decides autonomously about its investment, production and depollution strategies over time know- ing that investment/production generates pollution, and pollution is transboundary. The time horizon is infinite. Third, we allow for a rich set of geographic heterogeneities across states while the literature assumes identical states. We solve analytically the induced non-cooperative differential game under decentralization and fully characterize the resulting long-term spatial distributions. In particular, we prove that there exist a unique Perfect Markov Equilibrium. We further provide with full exploration of

3 - On Periodic Solution to Control Problems with Time-driven Switching
Anton Bondarev, Dmitry Gromov, Ekaterina Gromova

In this contribution, we consider the optimal control problem for a switched dynamical system. While such systems can exhibit rather complex behavior in the case of only one switch, the most interesting problem corresponds to the case, when the system undergoes an infinite number of switches. We study the limiting behavior of optimal solutions under such assumption and show that there are three types of solutions, two of which correspond to cyclic evolution of the system state and control. Such systems naturally arise in considering pollution problems, where greenhouse gases concentration undergoes seasonal fluctuations.

The work of D. Gromov and E. Gromova on the comptutation of optimal solutions was supproted by the Russian Science Foundation (project no. 17-11-01093). The work of A. Bondarev was supported by Key project Special Fund (KSF-E-63) of Xi'an Jiaotong-Liverpool University.

4 - Sliding Modes in Renewable Resources Dynamic Problems
Thorsten Upmann, Anton Bondarev

The presence of tipping points in ecological systems implies abrupt changes in the dynamics of the ecosystem (where the total collapse of the ecosystem may be considered as a special case of a switch from intact dynamics to the exhaling dynamics of a collapsing system). While sliding dynamics have been reported as generic for population systems, it has not yet been studied under which conditions sliding dynamics may result in an optimally controlled system. In this paper, we therefore explore the possibility of sliding dynamics in an optimal harvesting model. Applying the theory of piecewise-smooth systems to optimally controlled population dynamics, viz. the optimal harvesting strategy when the dynamics of the renewable natural resource switch at some threshold, we investigate if and when optimal sliding may emerge. To this end, we use a standard renewable-resource, optimal–harvesting model and consider different sources of possible regime switches: a change in the harvesting efficiency and a change in the growth rate of the stock. Both modifications result in a piecewise-defined evolution of the stock, and thus imply a piecewise-defined canonical system. Accordingly, novel types of dynamics and steady states emerge even in simple optimal harvesting model. Specifically, in case of a switch in the growth rate optimal sliding may result; that is, sliding dynamics emerge as part of the optimal solution. On the contrary, in case of a switch in the harvesting efficienc

■ TB-49

Tuesday, 10:30-12:00 - Virtual Room 49

Production and Maintenance

Stream: OR in Quality Management
Invited session
Chair: *Heletje van Staden*

1 - Lean Product Development - An empirical case study in the automotive industry
Ashkan Keykavoussi, Ahmad Ebrahimi

This article aims to propose a systematic approach of lean product development (LPD) and Product Development System (PDS), from the first phase of product and process development on customer needs, and lean design to the last phase of launching production. An integrated stage-gate system view of lean product development is presented with utilizing experts, quality and engineering processes, and tools. This system approach has been derived from intensive study of Ford's global product development system. In this study, a complete state-of-the-art review of subject literature in LPD and value and waste analysis in product development are conducted. As the concept of lean product development is to identify and eliminate any part of the product development process that does not add value, in this paper, lean and quality tools and techniques which can be used to eliminate LP waste and reduce production cost are discussed and applied that leads to increase customer satisfaction, improve end-product quality, and reduce lead time. Finally, in order to assess the effectiveness of the proposed method, this approach has been implemented in one of the automotive manufacturers as an empirical case study.

2 - Joint optimization of maintenance, inventory and control chart

Nadia Bahria, Imen Harbaoui Dridi, Anis Chelbi, Hanen Bouchriha

In this paper, we develop a joint quality control, production and maintenance policy for a production system producing conforming and nonconforming units. The considered system consists of a single machine subject to a degradation process that directly affects the quality of the produced items. Each lot produced by the machine is subject to a quality control with control chart. The preventive maintenance strategy consists in carrying out perfect maintenance actions every a such number of product quality inspections. A major maintenance (overhaul) is undertaken once the control limits are exceeded. On the other hand, a buffer stock is built-up at the beginning of the production cycle to hedge against potential future capacity shortage during repairs following the exceeding of the control limits. The objective is to determine the optimal values of the preventive maintenance period, the buffer stock size, the sample size, the sampling interval and the control chart limits, which minimize the average total cost per time unit.

3 - Degradation-threshold-shock model for systems considering repair service and replacement service

Minjae Park

The degradation threshold shock model for systems have been developed under warranty considering repair service and replacement service. We investigate the relationships between random shock and degradation process which are modeled by a time-scaled covariate factor and the relationship between various degradation processes. Fatal shock which needs replacement service for system immediately and nonfatal shock which needs repair service for failed parts are considered. For a nonfatal shock, there are two direct effects, slowly accelerations and sudden accretion jumps on the degradation levels. There are degradation limits for repair service and for replacement service, respectively. Degradation level may jump to the degradation limit for the replacement service or/ and may increase to the other degradation limit for repair serivce. In this study, we consider not only the degradation process but also random shock model and decision variables are determined for the degradation threshold shock model. An warranty service time for repair service and replacement service is considered with warranty service time limit to increase customers' satisfaction. Suppose that the system deteriorates with age, we illustrate the proposed approach using numerical applications and investigate the influence of relevant parameters on the optimal solutions for the maintenance policy.

4 - A failure-based data-driven approach for advancing preventive maintenance

Heletje van Staden, Laurens Deprez, Robert Boute

We investigate whether observed machine failures may be used to prescribe advancements of scheduled preventive maintenance interventions. By estimating future failures, we supplement and optimize current periodic maintenance practices by allowing for unscheduled preventive maintenance visits, based on the estimates. We model the problem as a finite horizon Markov decision process with a variable order Markov chain that captures the dependency of a machine's failures on both recent failures and preventive maintenance actions. We validate our model using an original equipment manufacturer data set and obtain policies that prescribe when to deviate from the planned periodic maintenance schedule. To improve our predictions for machine failure behavior with limited to no past data, we pool our data set over different machine classes by means of a Poisson generalized linear model. We observe average cost savings of 5% over current practices. The prescribed policies may be used to detect bad quality or poorly used machines that fail more often and therefore advise preventive maintenance actions accordingly, with cost savings up to 44% when compared to static periodic maintenance.

■ TB-50

Tuesday, 10:30-12:00 - Virtual Room 50

AI4RAILS III

Stream: The 2nd International Workshop on Artificial Intelligence for RAILwayS (AI4RAILS)
Invited session
Chair: *Zhiyuan Lin*

1 - Train delay and dwell pattern recognition using K-means clustering approaches: a comparison before, during and after Covid-19 lockdown

Zhiyuan Lin, Manuel Ojeda Cabral, Yulin Peng

K-means is one of the most widely used unsupervised machine learning approaches for clustering unlabelled data. In this research, real-world data on planned and actual arrival and departure times and other attributes of trains in the UK collected by Amey Consultants were analysed using K-means. The data are from 36 stations and cover several time periods in 2020, including before, during and after Covid-19 crisis hit.

We clustered the train's delay time patterns (as delay-station curves) based on features such as if in lockdown, route, operator, service group and time horizon. We are interested in the impact of lockdown conditions, particularly as lockdown meant substantial changes to rail service provision and passenger flow. The results vary and details will be reported in the workshop. In addition, we clustered the trains' station dwell times with the similar attributes above but grouped in several categories (e.g. station, route, peak/off-peak) to see if station dwell time was improved during the lockdown. The results support our assumption and are also verified by complementary statistical methods. We also discuss if classical statistical methods may over- or underperform clustering. For instance, will clustering discover patterns that are unable to be found by traditional statistical approaches? And what may be the reasons for a discrepancy between clustering and traditional statistics in the spirit of explainable AI?

2 - Real-time predictive analytics over space and time: A comparative analysis for delay prediction in railway transportation

Léon Sobrie, Veerle Hennebel, Bart Roets, Marijn Verschelde

Predictive analytics are increasingly used in managerial decision-making. In this paper, we compare data-driven and rules-based predictive analytics concerning railway transportation delays and investigate the heterogeneity in relative performance over space and time. The advocated data-driven methodology is based on a customized recurrent neural network structure and implemented in a real-time fashion on the total population of railway passenger transportation in Belgium. Our custom-built training data consists of over 500,000 sequences per month and includes uniquely rich information on the spatio-temporal interdependence between trains. The comparative analysis highlights how the relative (over)performance of data-driven analytics is context-specific as it increases with the complexity of the setting (e.g. related to the star-shaped network in Brussels or during peak hours). In addition, we show the benefits of higher flexibility when using data-driven approaches to cope with structural breaks such as the COVID-19 pandemic. Next to the new comparative findings, our deployment of a decision support system within Belgium's national railway infrastructure company Infrabel provides on-site validation of the value of tailored predictive analytics for decision-making in complex safety-critical settings.

3 - Exploring significant predictors of freight rail intermodal operation delays using causal machine learning
Juan Pineda, William McDonald, Wei Zheng, Francesco Viti

Despite advances on communication and control technologies in the railway sector, delays in freight rail intermodal operations are inevitable due to unexpected disruptions such as weather conditions or facility/train failures, generating negative impacts on the railway industry. Once a disruption occurs, train dispatchers should evaluate its severity on the overall service disturbance and try to reduce the performance losses by adjusting the timetable. Railway operations is a complex stochastic system which creates important difficulties in predicting its delays, therefore, identifying causes associated to these delays is vital to risk mitigation. In this study a suite of machine learning models are trained to predict the delays in freight railway intermodal operations, and the most appropriate model is used to explore the underlying significant predictors which cause these delays. The supporting dataset includes the intermodal operations of the Luxembourg National Railway Company network connecting several countries within the EU. The outcomes of this work will identify the key predictors explaining the risk of freight railway intermodal operation delays, and moreover, causal interrelationships between features will show how these predictors interact with one another and how these interactions lead to operation delays. The outcomes will be used in future works in order to optimise the intermodal operation of freight railway networks by suggesting actions to reduce delays

4 - Applying Machine Learning for Yard Departure Prediction
Niloofar Minbashi, Markus Bohlin, Carl-William Palmqvist, Behzad Kordnejad

Railyards are crucial nodes for re-arranging and dispatching freight trains in railway networks. Railyard departures impact the punctuality of other trains in the railway network. Therefore, infrastructure manager requires to predict the departure status of freight trains from the railyards in order to reduce the disturbances they may impose on the overall timetable. Railyard departure prediction is a complicated problem due to the complexity of railyard operations, in which many parameters and human decisions are involved. In this paper, we propose the application of machine learning algorithms to overcome this complexity. We compared the performance of two classification algorithms: decision tree, and random forest in predicting the departure status of freight trains. The results from random forest model, improved by synthetic minority oversampling technique (SMOTE), showed the highest accuracy for delayed and on-time departures. Currently, we are testing the model combining a larger data from wagon punctuality, train characteristics, and weather parameters to classify the departure status and predict the exact delay. Results from this model can be beneficial for the infrastructure manager in better allocation of capacity slots, and for the railyard operator in improved planning and utilization of the railyards.

■ TB-51

Tuesday, 10:30-12:00 - Virtual Room 51

Risk and resilience in sustainable supply chains

Stream: Sustainable Supply Chains
Invited session
Chair: *Bruna Mota*

1 - Hybrid model for designing sustainable flexible supply network for post-pandemic recovery
Harpreet Kaur

Abstract Recent pandemic has severely damaged the global economy and disrupted global chain networks. Many companies struggled to respond to these disruptions and restore their routine operations. It was further observed that during the pandemic sustainability took a back seat with many companies failed to achieve their sustainability targets. As we are slowly recovering from the pandemic, the strategic design of supply chain networks must evolve. There is a need to design more sustainable and flexible supply chain networks which are responsive to such disruptions in future. To address this concern, the paper proposes a hybrid model which attempts to integrate the short-term operational goals of minimizing the disruptions and operational cost with the long-term sustainable goal of building more resilient and flexible supply networks. The proposed model evaluates and assess the risk involved at various stages of a multi-tier supply chain. A fuzzy goal programming-based model is proposed which integrates the risk involved at each link while optimizing the multi-period, multi-item, multi-modal supply network under uncertainty and sustainability considerations. The detailed computational analysis is also carried out in the paper to study the impact of various factors on the resilience and sustainability of the overall network design.

2 - Dealing with the unpredictability of disruptions in the context of Supply Chain Resilience
João Ribeiro, Daniel Santos, Ana Paula Barbosa-Póvoa

Over the past year, Resilience has been an ever present topic due to the strain the pandemic caused to our lives. Our society faced an unpreceded global set of events for a period far greater than ever imagined. Companies had little time to adapt to this unpredictable scenario, which led to the success of some and the failure of others. Supply Chains that had incorporated the principles of Resilience, namely redundancy and flexibility, had some tools that could have been useful. However, it proved to be far from a universal approach due to the intricate disruptions that the contingency plans were not prepared for. The scarcity of resources and the trade-off towards maximum profitability under steady-state conditions turns the effort of designing and planning a SC into a challenging task. Our work tackles one of the most recognised hurdles when modelling in SC Resilience. The definition of disruptive events, which are known to be unpredictable (no probabilistic function known) and with high impacts. Therefore, we use robust optimisation to identify which facilities stoppages could cause the most significant harm and how can SC managers better prepare for such representative events. Our results show that one can use our approach to identify the weakest links in a SC and provide an alternative SC design while maintaining profitability under steady-state and disruptive scenarios.

3 - Sustainable supply chains under uncertainty: A flexible possibilistic modelling tool
Bruna Mota, Joost Stam, Inês Marques, Judith Timmer, Richard Boucherie, Ana Paula Barbosa-Póvoa

This work introduces a new flexible possibilistic programming (FPP) framework for sustainable supply chain decision-making, answering the call for research on the dynamic and uncertain nature of the supply chain. A general multi-objective fuzzy model is developed where a closed loop structure is modelled considering the three sustainability objectives: economic; environmental; and social. The model integrates strategic and tactical decision-making and considers uncertainty over a wide range of critical internal and external parameters. The proposed FPP framework enables to model different decision-makers risk strategies, using an α-cut formulation. The effect of different clusters of uncertain parameters are tested under a real-based case supply chain. The resulting supply chain design and planning decisions are discussed in detail and implications for a more robust and sustainable supply chain design and planning are presented. Results support the need to explicitly assess the impact of internal and external uncertain parameters. The decision-maker risk approach is found to be correlated with warehouses location, inventory levels, supplier location-allocation decisions, and re-manufacturing and collection rates.

■ TB-63

Tuesday, 10:30-12:00 - Virtual Room 63

Last minute changes 3

Stream: Last minute changes
Invited session
Chair: *Alexis Tsoukias*

1 - A Riemannian Gauss-Newton algorithm for the symmetric tensor rank approximation problem

Rima Khouja, *Bernard Mourrain*

A symmetric tensor is a higher order generalization of a symmetric matrix. The symmetric tensor rank-r approximation problem consists to find an approximation of a given symmetric tensor as a linear combination of r rank-1 symmetric tensors. This problem appears in many applications for instance in the areas of machine learning and biomedical engineering. We consider this approximation problem from a Riemannian optimization point-of-view, both for real and complex decompositions. We formulate this approximation problem as a non-linear least squares minimization problem. We present a new parametrization of the optimization set as a cartesian product of Veronese manifolds, and we describe an explicit retraction on this manifold. Using this formulation, we developp a Gauss-Newton algorithm, to solve locally the minimization problem. The initial point in this algorithm is chosen by a pseudo-determinist method, which provides a good initialization. This method is used to compute the spectral norm of a symmetric tensor. Further extensions to compute a good initial point, based on simultaneous matrix diagonalization approximation problem, are presented.

2 - A new mathematical model to the spread of stochastic investing information and to analyze the behavior of investors

Selma-Christina Belen, *Gerhard-Wilhelm Weber*

In this paper, we develop a mathematical model to solve and analyze the spread of the stochastic investing information and the behavior of the investors where the proportions of the population who invest or give up to invest or never hear the information of investing are obtained. We are concerned with the stochastic process of investing and its population dynamics and distinguish the whole population into three main sub-populations namely, active investors, passive investors and non-investors. Then, we distinguish the sub-population of passive investors into further three sub-populations namely, first type, second type and third type of passive investors. Thus, we have suggested five sub-populations of the population in total, to analyze the limiting behavior of each sub-population in the stochastic process of investing.

We give the general analytical and numerical solutions for the stochastic spread of investing depending on the arbitrary initial conditions. Hence, the proportion of each sub-population to the total population is formulated and can be calculated at any time of the stochastic process of investing.

3 - Enhancing feature selection in virtual metrology for semiconductor fabrication plants

Oussama Djedidi, *Valeria Borodin*, *Taki Eddine Korabi*, *Michel Juge*, *Agnès Roussy*

In semiconductor manufacturing, the increase of low-cost and high-volume demand for integrated circuits drives technological advances and high levels of automation, by increasingly strengthening the process control. Metrology tools are used to perform identical measurements of a set of key manufacturing parameters to help controlling production environments. Physical measurements done on wafers are costly and time-consuming, leading to the development of virtual metrology. The latter is based on the available historical observations and aims to predict one or several parameters of wafers according to their current states. One of the main challenges occurring when building a virtual metrology model is feature selection. Raw data collected on production machines and measurements sampled at high frequencies result in large datasets. Feature selection aims to preserve only the relevant features to accurately predict the metrology values.

In this work, we propose a new feature selection algorithm combining machine learning and metaheuristics. The proposed wrapper algorithm is composed of two stages. The first stage is a preliminary univariate analysis that filters out most of the noisy features. The second stage combines a genetic algorithm with a support vector regression model to find the best feature set for predicting the metrology values. Extensive computational experiments have been conducted to evaluate the performance of the proposed approach on an industrial dataset.

4 - The MCDA contribution and impact in environmental management

Panagiota Digkoglou, *Jason Papathanasiou*, *Alexis Tsoukias*, *Katerina Gotzamani*

The reflections of environmental management are constantly increasing worldwide and represent a concern that is expected most probably to escalate in the near future. Simultaneously, ensuring a decision-making process for achieving sustainability is crucial and essential considering current environmental, financial and social problems. The discipline of Multiple Criteria Decision Analysis (MCDA) has already contributed to a large extent as regards issues like sustainability, pollution and environmental management. Hence, during the last decades, there is an increasing number of MCDA publications relevant to environmental management, while there is a challenging necessity for real actions and change in the way we face environmental pollution. This paper reviews the contribution of MCDA studies relevant to environmental issues and examines the degree to which these studies have actually assisted the policymakers of environmental management to make decisions that are more responsible and sound. We analyzed 43 published review papers, including approximately 8.148 papers, while emphasis is given on the impact of such publications on the real cases and decision-making related to environmental pollution. Thus, a critical analysis of the environmental challenges has been developed as a second direction of this paper with the aim to compare the raising interest of MCDA papers with the real efforts and needs for a greener and more sustainable future.

Tuesday, 12:30-14:00

■ TC-01

Tuesday, 12:30-14:00 - Bulding A, Amphitheatre

Apostolos Burnetas

Stream: Keynotes
Keynote session
Chair: *Antonis Economou*

1 - Queues with Strategic Customers: Equilibrium, Social Welfare Optimization and Pricing
Apostolos Burnetas

The strategic behavior of customers has long been recognized as an important dimension in the modeling and analysis of production and service systems in Operations Research. Customers are rational decision makers who react to pricing, product quality and availability etc., and decide whether, when and how much of the product to buy so that they maximize their own utility. Incorporating customer behavior effectively internalizes the demand function and potentially leads to more realistic models for pricing, production planning and control.

When the system under consideration provides a service that involves waiting and queueing, analyzing the strategic behavior of customers becomes substantially more involved, because a customer's decision to join a queue affects the system congestion and the delay of the other customers as well, thus introducing externalities. Therefore, when customers are delay sensitive, their behavior affects and is affected by similar decisions of the other customers. Under this game-theoretic framework, the demand function emerges as an equilibrium strategy in appropriately defined games played between service providers and customers.

In this talk we will present some basic models from the area of queueing with strategic customer behavior. We will focus on the implications on pricing, both from a profit maximizing and a social welfare optimization perspective.

■ TC-02

Tuesday, 12:30-14:00 - Bulding A, Room A5

Portfolio Selection

Stream: Risk management in Finance
Invited session
Chair: *Tommaso Lando*

1 - Comparison of order statistics with respect to the second stochastic order
Idir Arab, Tommaso Lando, Paulo Oliveira

We study the problem of comparing ageing patterns of the lifetime of k-out-of-n systems, which translates to decide about a stochastic ordering relationship between order statistics. We discuss such relationships with respect to second-order stochastic dominance, obtaining sufficient dominance conditions through the verification of relative convexity with respect to a suitably chosen reference distribution function. This relative convexity defines different classes of distribution functions, and as expected the larger is the class, the stronger are the conditions to achieve the SSD ordering. We discuss the applicability of this method and characterize a test for the relative convexity, as this notion plays a central role in the proposed approach.

2 - Analysts' target price as the prediction for future returns
Aleš Kresta, Garegin Minasjan, Tomas Tichy

According to the efficient market hypothesis, it is believed that all publicly known information is reflected in the stocks' prices. In line with this hypothesis, it is impossible to achieve above-average yields in the long run when adjusted for the risk. On the contrary, the analysts from banks, specialized firms, etc., provide stock recommendations and state the fair value which they believe the stock should be priced at after one year from the issuance of the recommendation. In this contribution, we analyze 8 publicly traded stock titles on Prague Stock Exchange with 3324 recommendations from 52 analysts. We analyze the relationship between the fair value predicted by analysts and capital (or total return) in one year period from the recommendation issuance. By means of linear regression, we test whether the observed return in one year period is influenced by the relative difference between the actual price and predicted fair value. We find a statistically significant relationship, which means that the analysts can have some predictive power of the future returns.

3 - A revised version of the Cathcart & El-Jahel model and its application to CDS market
Hana Dvorackova, Davide Radi, Gabriele Torri, Vu Phuong Hoang

The paper considers the pricing of credit default swaps (CDSs) using a revised version of the credit risk model proposed in Cathcart and El-Jahel (2003). Default occurs either the first time a signaling process breaches a threshold barrier or unexpectedly at the first jump of a Cox process. The intensity of default depends on the risk-free interest rate, which follows a Vasicek process, instead of a Cox-Ingersoll-Ross process as in the original model. This offers two advantages. On the one hand, it allows us to account for negative interest rates which are recently observed, on the other hand, it simplifies the formula for pricing CDSs.The goodness of fit of the model is tested using a dataset of CDS credit spreads related to European companies. The results obtained show a rather satisfactory agreement between theoretical predictions and market data, which is identical to the one obtained with the original model. In addition, the values of the calibrated parameters result to be stable over time and the semi-closed form solution ensures a very fast implementation.

4 - Modelling Stochastic Parameters of the Generalised Autoregressive Score Model as Regime Shifts
Katleho Makatjane, Lawrence Diteboho Xaba

During the past decades, it has been demonstrated more than a few times that linear models are incapable to put in a nutshell non-linear dynamics of numerous time series data such as exchange rates and stock prices to declare fewer. As a result, to overcome this problem, non-linear models are adopted due to the fact that they have required qualities to apprehend non-linearities in a dataset. Nevertheless, a Markov-Switching-Autoregressive(MS-AR) model had become one of a prevalent non-linear models in time series and forecasting. Empirical research advocated that forecasting with non-linear process can be an encouraging alternative to traditional linear models. This is because linear models are often compared to non-linear models with mixed conclusions in terms of superiority in forecasting performance. Hence, the current study models stochastic parameters as regime shifts based on the predictive density at time T. To archive this objective, a non-stationary hybrid is estimated using Naive Bayesian estimates. Results of the study reveal a non-stationary trend in time-varying parameters over the sampled period and that the inclusion of non-stationary trend with respect to time significantly advances the empirical analysis. Extensions of these non-stationary time-varying parameters in the literature are quite complicated since it requires specification not only on how naive Bayesian parameters change over time but also with the bulk distribution component of parameters.

■ TC-03

Tuesday, 12:30-14:00 - Bulding A, Room 3A

Data Science and Analytics - On site session

Stream: Data Science and Analytics (contributed)
Contributed session
Chair: *Lisa Schetgen*

1 - Does multiple periodicity exist within a trading activity?
Josip Arneric

Better understanding of multiple seasonality patterns can be very helpful in capturing dynamics of trading volume and consequently improving the performance of trading algorithms and reducing the transaction costs. It is well known that high-frequency data exhibit periodic patterns in trading activity, i.e. intraday trading volume seasonality. Although multiple seasonality in price dynamics have been conducted in the literature there is a lack of studies covering multiple seasonality of trading activity considering intraday volume observations. Namely, advances in electronic trading have enabled recording high-frequency data and it is of great interest to discover not only if multiple seasonal components exist in trading volume, but also which component is most time-varying, which seasonal components are the strongest or weakest. For the same reason multiple STL algorithm based on Loess is employed due to its advantages against traditional decomposition methods.

2 - Forecasting the rail freight transport intensity on Corridor X
Milos Milenkovic, Natasa Milosavljevic, Bojovic Nebojsa, Dejan Lutovac

Balkan Silk Road should provide a rapid connection from the Greek Port of Piraeus through the Balkan further to EU markets. Railroad Corridor X linking Central Europe with Aegean Sea via Hungary, Serbia, FYR Macedonia and Greece represents a crucial component for the development of Balkan Silk Road. The rising demand for transport services through the Corridor X is directly influenced by the increasing demand for final and intermediate products from Asia and Europe and vice versa. In order to provide an adequate support for planning of transport infrastructure and service on Corridor X it is important to consider the intensity of freight flows in future. Therefore, in this paper we analyzed the volumes of import and export flows on four main border crossings that represent the enter and exit nodes of Serbian part of Corridor X. On a set of eight-time series, where each is composed from 120 monthly observations (2011-2020), we compared a number of advanced forecasting techniques in order to obtain a forecast of freight volumes for the period of one year ahead. Specifically, support vector machines (SVM) and artificial neural networks (ANN) are developed and compared with traditional ARIMA mode. For each time series the most reliable forecast is selected based on a set of performance criteria.

3 - Conceptualising the potential of big data analytics to facilitate discrete-event simulation modelling in smart mobility
Mario Jadric, Maja Cukusic

To understand, monitor and explore the potential of new (smart) solutions for urban environments ex-ante, numerous managerial and ICT tools are used by city planners. Acknowledging the challenges and sourcing support in their Big Data journies, they are leveraging data and analytics in planning new smart city initiatives. As novel concepts and tools such as Big Data Analytics (BDA) reach a sufficient maturity level, these could be used to boost the potential and relevance of standard and well-established operational research techniques such as Discrete-Event Simulation (DES). A literature review on the combined use of BDA and DES results in a relatively small number of papers with most of the studies in the field of manufacturing, and only two addressing the context of smart cities. For this reason, to map out the links between BDA and DES based on relevant findings, literature review for each of the topics in the context of smart city was done. The results indicate that both BDA and DES in smart cities are used within the mobility sector. Thus, a case study from the field of smart mobility was set up to assess the role of BDA in building simulation models at the level of aggregate building blocks of the simulation model. The main contribution of the paper is the formulation of a conceptual model mapping specific BDA techniques such as process mining and data mining to distinct stages of DES model development in the specific context of smart mobility.

4 - Developing a detection and interpretation tool for rumors regarding COVID-19 on Twitter
Lisa Schetgen, Bram Janssens, Matthias Bogaert

Nowadays people use social media as one of their primary sources of information. Considering encountered misinformation can be detrimental to communications made by official instances, it is of major importance to detect potential rumors as soon as possible. The introduction of the term 'infodemic' by the World Health Organization highlights the magnitude and severity of the spread of misinformation during the COVID-19 pandemic. The aim of this study is to introduce a start-to-end rumor detection framework for COVID-19-related discussions on Twitter. Specifically, we present an approach for collecting Twitter data, building a suited detection model and gaining insights into the most important rumors. We investigate different traditional machine learning, deep learning and transformer models to determine which model is best suited for the classification of tweets into rumors and non-rumors in the context of COVID-19. Furthermore, we use a joint dimensionality reduction and clustering algorithm to cluster the COVID-19-related tweets into homogenous groups. Finally, we combine the results of the two aforementioned analyses to discover which clusters contain most rumors.

■ TC-04

Tuesday, 12:30-14:00 - Bulding A, Room 3B

Healthcare Services

Stream: ORAHS: OR in Health and Healthcare
Invited session
Chair: *Mariusz Kaleta*

1 - A Stochastic Nash equilibrium problem for medical supply competition
Georgia Fargetta, Laura Rosa Maria Scrimali, Antonino Maugeri

In this paper, we study the competition of healthcare institutions for medical supplies in emergencies caused by natural disasters. In particular, we develop a two-stage procurement planning model in a random environment. We consider a pre-event policy, in which each healthcare institution seeks to minimize the purchasing cost of medical items and the transportation time from the first stage, and a recourse decision process to optimize the expected overall costs and the penalty for the prior plan, in response to each disaster scenario. Thus, each institution faces a two-stage stochastic programming model that takes into account the unmet demand at the first stage, and the consequent penalty. Therefore, the institutions simultaneously solve their stochastic optimization problems and reach a stable state governed by the stochastic Nash equilibrium concept. We then present an alternative two-stage variational inequality formulation. Finally, we discuss some numerical illustrations applying the progressive hedging algorithm.

2 - Rich Location Routing Problem with application to Multi-hospital network
Ons Saidi, Malek Masmoudi, Koffi Cobbold, Edgar Alfonso Lizarazo, Pascal Albert

Multi-hospital network, denoted Territory Hospitals Group (TGH) in France, became a trendy organizational structure allowing a collaborative logistics strategy between hospitals in order to optimize the logistics processes by rationalizing storage means and distribution circuits. We address the design and management of the TGH logistics network as a specific Location Routing Problem (LRP) where strategic decisions related to warehouses location are interdependently taken with tactical and operational decisions related to hospitals demands assignment to warehouses and design of vehicle routing serving these demands. The objective is to minimize the total cost including warehouses exploitation costs, vehicles exploitation costs and routing costs. We consider a particular variant combining several realistic constraints that, to the best of our knowledge, has not been considered simultaneously in LRP literature: one parking, multiple warehouses, multiple products, heterogeneous vehicles, pick-up and delivery demands and time windows. We provide a mixed-integer linear model for the problem and use Cplex to solve realistic instances. A sensitivity analysis regarding warehouses and vehicles specificities and time windows tightness is provided. The work in process is to develop a multi-stage stochastic approach to deal with demand variability, and make the validation on real data from the TGH of Limousin in France.

3 - Optimization of non-pharmaceutical interventions in networked infectious diseases spreading model under different spatial and decision granularity
Mariusz Kaleta, Robert Olszewski, Tomasz Sliwinski, Izabela Zoltowska, Karolina Nowak, Malgorzata Kesik-Brodacka

We consider the problem of planning non-pharmaceutical interventions to control infectious diseases spreading. Based on classical compartmental models, we propose a new networked model that takes into account the spatial structure and mobility of the population. Various objectives are considered, including minimization the total number of deaths or symptomatic cases, as well as minimization the maximum daily symptomatic cases. The resulting model is a large scale nonlinear and non-convex optimization problem. We analyze how the granularity of the disease spreading model affects its computational complexity and quality of solutions. We also consider the granularity of decisions regarding non-pharmaceutical interventions. Since, the computational burden significantly increases along with granularity of spreading model and decisions we look for reasonable trade off between minuteness of the model and the quality of the solutions obtained. We test our model for COVID-19 real data covering Poland on different levels of administrative division.

■ TC-05

Tuesday, 12:30-14:00 - Building Δ, Room Δ105

OR for Development and Emerging or Developing Countries

Stream: OR for Development, Developing Countries and Sustainable Development
Invited session
Chair: *Herman Mawengkang*
Chair: *Gerhard-Wilhelm Weber*

1 - Knowledge economy in Central and Eastern European countries: a multi-criteria approach
Sandra Milanovic, Jelena J. Stanković, Ivana Marjanović, Milica Jovanovic, Saša Drezgić

In the modern understanding of development dynamics and sustainability education and science are one of the key determinants. Although contemporary literature encompasses various indicators of progress in the knowledge economy (KE), there is a lack of overall measure that enables a comprehensive quantification of all KE aspects. Therefore, the paper aims to create a composite index for evaluation of KE in Central and Eastern European (CEE) countries involving 20 indicators classified into four categories: institutions for innovation, skills for innovation, innovation system, and ICT infrastructure. Composite index creation is conducted using multi-criteria analysis, applying PROMETHEE method. The results indicate that CEE countries that are EU members have significantly better results regarding the overall assessment of the KE, and the best-ranked country is the Czech Republic. The Balkan countries are at the very bottom of the table, with Albania having the lowest composite index of KE progress. The contribution of this study is reflected in the proposition of the composite index that covers a large number of aspects of the KE and can have twofold implications. Theoretically, the proposed methodology emphasizes the possibilities and advantages of applying the methods of multi-criteria analysis in this area. Practically, the proposed index can provide guidelines to policymakers and facilitate the decision-making process towards a knowledge-based economy and society.

2 - Aggregate Production Planning with Human Factors, Overtime and Outsourcing Options under Uncertain Seasonal Demand
Gerhard-Wilhelm Weber, Selma Gütmen, Alireza Goli, Erfan Babaee Tirkolaee

Aggregate production planning (APP) is a medium-range production and employment planning that deals with the main challenges of manufacturing industries, such as production and outsourcing quantities, hiring and lay-off rates and inventory levels. On the other hand, sustainable development plays a key role in the problem based on global issues, particularly in environmental aspects. This study develops a novel multi-objective mixed-integer linear programming model to formulate the sustainable APP problem with overtime and outsourcing options under fuzzy seasonal demand. The objectives are to concurrently minimize total cost of the production system, minimize total environmental pollution and maximize customers' satisfaction level. To deal with the multi-objectiveness of the model, the augmented epsilon-constraint technique is implemented. A numerical example is then investigated to test the performance and validity of the proposed mathematical model. Finally, the behavior of the objective functions is evaluated against the fluctuations of key parameters based on unstable real-world situation and managerial insights and decision aids are suggested. One novelty we shall discuss consists in our refined "matrix questionnaires" by means of which we will lead APP deeply into Human Resource Management.

■ TC-06

Tuesday, 12:30-14:00 - Building Δ, Room Δ103

Heuristics, mathheuristics and hyperheuristics

Stream: Heuristic Optimization
Invited session
Chair: *Patrick Huber*

1 - An adaptive call center routing policy
Siqiao Li, Ger Koole

Multi-skill/channel call centers are more efficient than single-skill ones but need routing to exploit this efficiency gain. In practice, routing policies that are written in ACD (Automatic Call Distributor) do not depend on current service levels (SLs) or staffing levels. Real-time adjustments are still done manually by intra-day managers to achieve the daily service level agreements (SLAs). However, the adjustments are mainly experience-based, barely supported by any sound algorithm. In this paper, we propose a routing policy that adapts itself to changes in the call center environment without human interaction. Numerical results showed that the proposed policy is efficient in balancing the SLs of different skills to meet their SLAs and in balancing the occupancy of agents as well.

2 - Robust Bin Packing with Budgeted Uncertainty
Noam Goldberg, Marin Bougeret, Gyorgy Dosa, Michael Poss

We consider robust variants of the bin packing problem with uncertain item sizes. Specifically, we consider two uncertainty sets previously studied in the literature: budgeted uncertainty in which at most gamma items deviate and the knapsack uncertainty set, which bounds the total amount of deviation in each bin. We show that a variant of the next-fit algorithm is a 2-approximation for the knapsack uncertainty set, and another variant of this algorithm is a 2-gamma approximation for the budgeted uncertainty model. This first result motivates the question of the existence of a constant approximation factor algorithm under budgeted uncertainty. Our main result affirms this question using a dynamic-programming based algorithm to prove a 4.5 approximation factor.

3 - A redefinition and solution of the Urban Transit Routing problem as a heterogeneous electrical variant
Patrick Huber, Uli Goehner

The Heterogenous Electric - Urban Transit Routing Problem (HE-UTRP) extends the highly complex problem of the Urban Transit Routing Problem (UTRP), which is originally concerned with finding efficient travelling routes for Public Transport (PT) systems. The enhancements made focus on the transformation of public bus transportation systems to electric mobility.

This paper defines HE-UTRP and presents a framework, which is used for the analysis, generation and optimization of a PT route network with heterogeneous characteristics and therefore the generation of solution candidates for the HE-UTRP. The heterogeneity refers to both the vehicle fleet to be used and the charging infrastructure. In addition to the analysis of different charging technologies and charging locations, the approach enables a transformation process towards electrification of PT systems by presenting substitution scenarios as well as the resulting cost structure.

The created framework, based on a Sequence-based Selection Hyper-heuristic - with Great Deluge (SS-GD), is evaluated with varying objective functions and problem instances for the UTRP, HE-UTRP and a related homogeneous problem known as the Electric Transit Route Network Design Problem (E-TRNDP), thereby demonstrating its capability/effectiveness. With respect to the E-TRNDP new optima are generated for common problem instances.

Finally, the SS-GD is investigated for robustness under the variation of external influence parameters.

■ TC-08

Tuesday, 12:30-14:00 - Building Δ, Room Δ101

Quality and Maintenance

Stream: OR in Quality Management
Invited session
Chair: *Michele Urbani*

1 - A branch and price algorithm for the integrated production and maintenance scheduling problem
Sven Pries

In modern industrial production, all day processing is common practice. To ensure the high availability of production capacities and to hedge against the impact of random failures, preventive maintenance (PM) needs to be scheduled directly while shifts are working. PMs increase a machine's remaining useful life while job processing depletes it and increase the probability of failure. Both are competing for time in the planning horizon in which they occupy the machine. Scope of this work is the trade off between the total PM time and the cumulative delays by random failures.

Assuming jobs which cannot be interrupted by PMs, a single machine environment minimizing the expected makespan can be expressed as an assignment problem of jobs to the interval between two consecutive PM activities. This can be reformulated using Dantzig-Wolfe-Decomposition and solved with a branch and price algorithm. To accelerate the solution procedure a resource-constrained shortest-path problem and different branching schemes are used.

2 - Maintenance optimization on a network flow problem: a bi-objective approach
Michele Urbani, Matteo Brunelli, Antti Punkka

Preventive maintenance activities are often the cause of downtime of technical multi-component systems. To minimize maintenance costs and maximize productivity, maintenance tasks are often grouped and carried out simultaneously. We consider the problem of obtaining an optimal maintenance schedule when the multi-component system can be modelled as a directed graph, where nodes represent machines or workers, and edges represent the exchange of material, information, or work between these nodes. To find efficient maintenance schedules, we formulate a bi-objective optimization problem, which considers the limited availability of maintenance personnel, and we propose an algorithm that finds a set of maintenance schedules, which are Pareto-optimal in terms of costs and productivity - measured in system throughput. Through a sensitivity analysis, we show that adding repairers improves system productivity, at the expense of increased maintenance costs and increased idle time of some resources. Besides solving the Pareto-optimal schedules, we show how the developed model is useful in maintenance personnel planning, and we outline limitations and future developments of the present work.

■ TC-21

Tuesday, 12:30-14:00 - Virtual Room 21

Methodological and practical contributions of Soft OR/PSMs to Policy Making - Session A

Stream: Soft OR and Problem Structuring Methods
Invited session
Chair: *Ine Steenmans*
Chair: *Irene Pluchinotta*

1 - Cognitive Maps in Conflict Transformation and Management
Berkay Tosunlu, Alexis Tsoukias

The paper analyses the use of cognitive maps as tools for managing and transforming conflicts. The basic idea consists in creating sequences of cognitive maps allowing to derive value trees of the relevant stakeholders involved in the conflict under consideration. Such value trees could be used as input for knowledge and concept structures in formal design theory methods aiming at constructing appropriate conflict transformation policies.

2 - Combining Cognitive Mapping and Agent-based Modelling for detecting barriers to environmental policy implementation: the case of Nature-based Solution.
Raffaele Giordano

NBS has become a valid alternative to grey infrastructures for coping with climate-related risks in urban and rural areas alike. However successful NBS seem to be, moving from designing to implementing NBS remains a challenge due to several barriers. Among the others, this work focuses on the collaboration barriers. NBS implementation is a complex issue, whose effectiveness does not depend exclusively on the capacity and resources of the involved decision-makers, but also the number and quality of the relationships with each other. Divergent views about NBS implementation and the expected impacts might lead to conflict if the decision-makers and stakeholders perceive the NBS implementation as directly affecting their interests. Actions are needed to enable the transition from conflict to cooperation for NBS implementation.This work describes a methodology based on the combination between cognitive mapping (CM) and agent-based modelling (ABM) for overcoming the collaborative barriers and to facilitate NBS implementation. Specifically, CM was used to elicit and structure the decision-makers' behavioural models and to detect similarities and differences; ABM was implemented to formalize the decision rules, to detect potential conflicts due to divergent objectives and to assess the impacts of conflicts on NBS implementation. Finally, interventions scenarios were simulated and assessed aiming at defining actions for enabling the transition from conflict to cooperation.

3 - Eliciting policy causal mechanisms from a systems perspective: A case study of housing policy design in UK
Koko Zhou

Effective public policy design is fundamental to achieve best policy outcomes. Increasing literature stresses the importance of causal mechanisms in policy design. However, limited tools are provided to address the complex nature of policy causal mechanisms that involve multiple level actors and social systems. A systems perspective could be promising to elicit causal mechanisms that is critical to decrease unintended consequences and achieve better policy outcomes. Through a case study of the UK's housing sector, this paper develops a qualitative systems model mapping the causal mechanisms of policy and organisation' decision-making based upon a series of virtual participatory group model building (GMB) workshop sessions. This paper demonstrates GMB workshops as a system thinking tool to elicit causal feedback mechanisms to inform early-stage policy design with a systems perspective. The research shows critical pathways for building up organisations' capacity to deliver policy goals which are often by nature long-term. Intervention points of policy design based on the systems map are discussed. The paper concludes with limitations and implications for future research.

4 - The importance of eliciting and comparing stakeholders' system boundary perceptions for problem structuring and policy-making
Irene Pluchinotta, Giuseppe Salvia, Nici Zimmermann

Differences in system boundaries and problem framings are unavoidable in multi-organizational policy-making. These differences could lead to a polarisation of viewpoints, reducing the effectiveness of a policy or to the misperceptions of a system creating confusions of needs and distort evaluation. This talk aims to understand stakeholders' perceptions of system boundaries and problem framings, by systematically comparing different stakeholder groups' causal maps around the same shared concern. Bridging notions from Operational Research, System Dynamics, and Organisational Studies, the comparison is based on a novel type of thematic analysis of Causal Loop Diagrams (CLDs) built with each stakeholder group on their perceptions of a given system. The proposed integrated approach combines qualitative with quantitative analysis, such as the centrality of the variables and the structure of the CLDs. Such CLDs comparison provides an intuitive way to visualize differences and similarities of the thematic sectors, underlining factors influencing the shared concern. This could be considered a starting point for a more holistic understanding of the system and, consequently, of a decision/policy-making process. The research is based on the activities carried out for an urban regeneration case study in Thamesmead, London, United Kingdom.

■ TC-22

Tuesday, 12:30-14:00 - Virtual Room 22

Nash equilibria in Stackelberg models

Stream: Bilevel Optimization
Invited session
Chair: *Francesco Caruso*
Chair: *Jacqueline Morgan*

1 - Stackelberg approximate equilibria and potential games
Lucia Pusillo

In this paper we study approximate solutions in Stackelberg problems. Here we distinguish between pessimistic and optimistic Stackelberg equilibria and approximate ones. We show that the sets of pessimistic equilibria is very different from the set of optimistic one and so this is for approximate solutions even if the considered games have the same unique equilibrium. We prove that the exact pessimistic Stackelberg solution is not an approximate one, instead this fact does not happens for optimistic solutions. In fact the optimistic solutions are nested instead the pessimistic aren't. In spite of this, defining approximate equilibria in this way seems to be the most natural to have economic applications. We study also hierarchical potential game and we relate the approximate Stackelberg solutions and the approximate maximum point of the potential function . We prove that the set of pessimistic or optimistic equilibria of the game are the same of the corresponding pure coordination game and they correspond to the set of maximum point for the potential function. Furthermore the set of approximate Stackelberg equilibria do not coincide with the superlevels of the potential function. Furthermore we give some notions to have a generalization to multicriteria games.

2 - A general constructive method for subgame perfect Nash equilibria in Stackelberg games
Francesco Caruso, Maria Carmela Ceparano, Jacqueline Morgan

In one-leader one-follower Stackelberg games, multiple Subgame Perfect Nash Equilibria (henceforth SPNE) could arise when the optimal reaction of the follower to any choice of the leader is not always unique, that is when the best reply correspondence of the follower is not a single-valued map. In this presentation we introduce a general constructive method in order to approach an SPNE that relieves the leader of knowing the follower's optimal reactions and that permits to overcome the difficulties deriving from the possible multiplicity of the follower's optimal reactions. More precisely, we consider a general scheme of perturbation of the Stackelberg game which allows to construct a sequence of perturbed games where the follower's best reply correspondence is single-valued and we determine the conditions which guarantee that the limit of a sequence of SPNEs associated to these perturbed games generates an SPNE of the initial game. The results incorporate those obtained in Morgan and Patrone 2006 (involving the Tikhonov method) and in Caruso, Ceparano and Morgan 2019 (involving the Proximal method). Moreover, we present their application to a perturbation of the Stackelberg game relying on an altruistic behavior of the players.

3 - Best response approaches for optimization problems with equilibrium constraints
Maria Carmela Ceparano, Francesco Caruso, Jacqueline Morgan

We consider a one-leader two-follower Stackelberg game, where for each choice of the leader the followers face a simultaneous-move game having a unique Nash equilibrium. The leader, who anticipates the reaction of the followers, maximizes his payoff function and tackles an optimization problem with equilibrium constraints. First we consider the situation where the leader's payoff depends on the followers' actions but the followers' payoffs do not depend on the leader's actions. We present a theoretical "best-responses-based" method which globally converges to a solution of the associate leader's problem. By best-response-based method we mean methods exploiting affine relaxations of the classical best response algorithm for Nash equilibria. Then, the convergence of a derivative-free numerical method for the leader's problem will be analyzed, in particular when the followers face a potential or an antipotential game. Finally, we highlight the difficulties related to the above mentioned issues in the situation where the followers' payoffs depend on the leader's actions.

4 - Existence results for stochastic hierarchical models
Lina Mallozzi

We consider a n-player game with aggregative structure, namely when the payoffs depend on the strategies of the opponent players through an aggregator function. We assume that some players behave as leaders in a Stackelberg model and the same interaction behavior between players at the same level of hierarchy. A particular case, that appears in many applications, is to consider the leaders, as well the followers, acting non-cooperatively between themselves and solving a Nash equilibrium problem. We assume an exogenous uncertainty affecting the payoffs and obtain existence results for the stochastic resulting game. Some examples are illustrated.

■ TC-23

Tuesday, 12:30-14:00 - Virtual Room 23

Derivative-free Optimization: Methods and Applications in Industrial Problems

Stream: Derivative-free Optimization
Invited session
Chair: *Riccardo Pellegrini*
Chair: *Matteo Diez*

1 - Airfoil Optimization via Nonlinear Design-space Dimensionality Reduction
Alexander Schneider, Umberto Iemma, Andrea Serani, Matteo Diez

In shape optimization, design improvements significantly depend on the dimension and variability of the design space. The dimensionality and variability depend on the shape modification method used to modify the geometry undergoing optimization. High dimensional and variability spaces are more difficult to explore, but also usually allow for more significant improvements. In this work the efficacy of two dimensionality reduction methods, namely the principal component analysis (PCA) and the deep auto encoder (DAE), in reducing the design space dimension while maintaining a high variability is investigated. The investigation is performed while optimizing the shape of a NACA 0012 airfoil via continuous derivative-free genetic algorithm considering three design spaces. The first one is a full-dimensional design space as defined by nested free-form deformation technique with 66 design variables. The second and the third ones are the reduced design spaces as identified by the PCA and the DAE with 5 and 6 design variables, respectively. The airfoil performances are assessed through potential flow simulations. The optimization problem aims to the minimization of the resistance under the constraint of the airfoil providing a constant lift force. The optimizations are performed with a derivative-free genetic algorithm and the results of the optimization are compared to assess the performance of the design space reduction methods.

2 - Hull-shape Optimization of an Autonomous Surface Vehicle via Multi-fidelity Gaussian Process and Adaptive Sampling
Simone Ficini, Umberto Iemma, Riccardo Pellegrini, Andrea Serani, Angelo Odetti, Massimo Caccia, Matteo Diez

The hydrodynamic optimization of an Autonomous Surface Vehicle (ASV) via derivative-free optimization algorithm is presented for the minimization of the advancing resistance. The ASV is named Shallow Water Autonomous Multipurpose Platform (SWAMP), it is a 1.24 m long vehicle designed for the acquisition of environmental parameters in the extremely shallow waters of wetlands (e.g., rivers and lakes). The minimization of the resistance allows to increase the maximum speed and the operative range. The optimization is performed modifying the hull-shape via a free-form deformation technique using 12 design variables. Several constraints are considered to maintain the SWAMP external dimension limited for transportability and internal dimension large enough to accommodate the payload (e.g., instrumentation). The hydrodynamic performance of the SWAMP is assessed with a potential-flow solver coupled with the rigid body equations of motion. The numerical simulations are used to train a variable-fidelity Gaussian process metamodel (MFGP). The fidelity level is defined by both the computational grid size and the convergence tolerance of the coupling solver between hydrodynamic loads and motions. A parallel-infill adaptive sampling method is used to add training points where it is most informative, selecting the most convenient fidelity level. Finally, the optimization is performed on the response surface provided by the MFGP by a deterministic particle swarm optimization algorithm.

3 - Multifidelity Resource Aware Active Learning for Engineering Optimization
Laura Mainini, Francesco Grassi, Giorgio Manganini, Michele Garraffa

Optimization problems in engineering usually require many evaluations of expensive black-box objective functions. Bayesian Optimization methods can improve the efficiency of the optimization procedure by actively learning a surrogate model of the objective function that leverages the information gathered along the search path to reduce the amount of required expensive function evaluations. Efficiency can be further improved in a multifidelity setting, where cheaper but potentially biased approximations of the function can be used to assist the search of optimal points. This talk presents the Resource Aware Active Learning (RAAL) algorithm, a novel multifidelity Bayesian scheme we developed to accelerate the optimization of black box functions through the optimal exploitation of parallel computing architectures. At each optimization step, the RAAL computes the set of best sample locations and the associated fidelity sources that maximize the information gain to acquire during the parallel evaluations of the objective function, while accounting for the limited computational budget. The sampling task is formulated as a discrete optimization problem modelled as a Mixed-Integer Linear Programming model which selects a subset of the candidate points within the feasible domain. The scheme is demonstrated for several benchmark problems: we observe that the RAAL strategy optimally seeds multiple points at each iteration, which allows for a major speed up of the optimization task.

4 - Ship-hull Optimization via Multi-Fidelity Derivative-Free Line-Search Algorithm
Riccardo Pellegrini, Giampaolo Liuzzi, Stefano Lucidi, Francesco Rinaldi, Andrea Serani, Matteo Diez

This work presents a multi-fidelity coordinate-search derivative-free algorithm for non-smooth constrained optimization (MF-CS-DFN), in the context of simulation-based design optimization (SBDO). The objective of the work is the development of an optimization algorithm able to improve the convergence speed of the SBDO process. The proposed algorithm is of a line-search type and can handle objective function evaluations performed with variable accuracy. The algorithm automatically selects the accuracy of the objective function evaluation based an internal steplength parameter. The MF-CS-DFN algorithm starts the optimization with low accuracy and low-cost evaluations of the objective function, then the accuracy (and evaluation cost) is increased. The method is coupled with a potential flow solver whose accuracy is determined by the computational grid size. No surrogate models are used in the current study. The algorithm is applied to the hull-form optimization of a destroyer-type vessel in calm water using 14 hull-shape parameters as design variables. The optimization aims at the total resistance reduction. Seven refinements of the computational grid are used by the multi-fidelity optimizations. Four setups of the MF-CS-DFN algorithm are tested and compared with an optimization performed only on the finest grid.

■ TC-24

Tuesday, 12:30-14:00 - Virtual Room 24

Vector and Set Optimization II

Stream: Vector and Set Optimization
Invited session
Chair: *Gabriele Eichfelder*
Chair: *Marcin Studniarski*

1 - Comparison of two higher-order epiderivatives for set-valued maps
Marcin Studniarski
We compare two definitions of higher-order epiderivatives for set-valued maps, introduced in two papers by N.L.H. Anh [Positivity 20 (2016), 499-514] and [Positivity 22 (2018), 1371-1385]. We present a new relation between them without using the assumption of higher-order directional compactness. Some examples are included.

2 - An efficient descent method for locally Lipschitz multi-objective optimization problems
Bennet Gebken
In this talk, we propose a new descent method for nonsmooth MOPs with locally Lipschitz objective functions. The descent direction is based on epsilon-subdifferentials, which are iteratively enriched with gradient information until a satisfying direction is found. Combined with a modified Armijo step length, we prove convergence of the method to points that satisfy a necessary condition for Pareto optimality. A comparison to the multiobjective proximal bundle method suggests that our method needs fewer subgradient evaluations but more function evaluations. Finally, the descent method is inserted into the subdivision method to compute the whole Pareto set.

3 - Euler-Lagrange equations: the multiobjective case through a set-valued approach
Daniela Visetti
We provide some answers to the problem of minimizing an integral functional of a vector-valued Lagrangian on a set of admissible arcs with given endpoints. The vector-valued problem is embedded into a set-optimization problem, so that a complete lattice approach is considered. It is so possible to give a definition of a minimizer and of an infimizer, as two completely different concepts.

Set-valued Euler-Lagrange equations are obtained. Following the guidelines of the classical results, under convex and coercive hypotheses an existence result of an infimizer is proved. Moreover, the constrained problem is studied in the isoperimetric case. An application is given to the optimization of the shape of energy-saving buildings.

This is a joint work with Frank Heyde, Technische Universitaet Bergakademie Freiberg.

Acknowledgments: This project was funded by VerTecMVP, Free University of Bozen.

4 - A Decision Space Method for Multiobjective Convex Quadratic Integer Optimization
Gabriele Eichfelder, Marianna De Santis
We present a branch-and-bound algorithm for minimizing multiple convex quadratic objective functions over integer variables. Our method looks for efficient points by fixing subsets of variables to integer values and by using lower bounds in the form of hyperplanes in the image space derived from the continuous relaxations of the restricted objective functions. We show that the algorithm stops after finitely many fixings of variables with detecting both the full efficient and the nondominated set of multiobjective strictly convex quadratic integer problems. A major advantage of the approach is that the expensive calculations are done in a preprocessing phase so that the nodes in the branch-and-bound tree can be enumerated fast. We show numerical experiments on biobjective instances and on instances with three and four objectives.

■ TC-25
Tuesday, 12:30-14:00 - Virtual Room 25

Topics in Stochastic and Robust Optimization

Stream: Stochastic and Robust Optimization
Invited session
Chair: *Steffen Rebennack*

1 - Incremental Maximum Likelihood Estimation of Noisy Gaussian Random Walk
Vytautas Dulskis, Leonidas Sakalauskas

Although stochastic flows are ubiquitous in operational research tasks, the theoretical characteristics of such flows have not yet been sufficiently explored when they are perturbed by observational noise. In this work, a Gaussian random walk perturbed by additive Gaussian noise is considered, both of which have unknown variances. We propose a maximum likelihood method based recursive algorithm for the incremental estimation of unknown model variances using noisy observations. It employs the derivative of a specifically parameterized logarithmic likelihood function to derive an explicit update rule for the estimates. The proposed algorithm is not only an efficient solver of the problem under consideration but also provides insight into the construction of incremental maximum likelihood estimation algorithms for more complex models.

2 - Chance constrained model predictive control of parabolic PDE systems with random parameters
Ruslan Voropai, Abebe Geletu, Pu Li

Deterministic model predictive control (MPC) has been well studied and widely applied in a variety of disciplines. However, the solution of a deterministic MPC depends heavily on the accuracy of the system model which usually contains random parameters. Therefore, it is necessary to design a stochastic MPC to derive a reliable solution. In this study, we present a chance constrained MPC for the control of parabolic partial differential equation (PDE) systems with random coefficients. The inequality constraints of the time- and space-dependent state variables are defined in terms of chance constraints. Using a discretization scheme, the resulting high-dimensional chance constrained optimization problem is solved by our recently developed inner-outer approximation approach. We demonstrate the viability and versatility of the proposed MPC through a case study of tumor hyperthermia treatment, where randomness arises from thermal conductivity coefficients, characterising heat flux in human tissue.

3 - Dual approaches to multistage stochastic linear programs
Yi Cheng, Alexander Shapiro

In this talk, we discuss the dual of a multistage stochastic linear program and computational approaches to solving it. We start with introducing Dual SDDP, which solves dynamic programming equations for the dual and computes deterministic upper bound for the optimal value of the problem. Importantly, this method does not require that the dual has relatively complete recourse(RCR). In some applications the considered multistage stochastic programs have a periodical behavior with discount. Through construction of the dual of the periodical formulation of the infinite horizon problem, we show that it is possible to compute a deterministic upper bound efficiently even when the discount factor is close to one. Finally, we demonstrate numerical results of an inventory control problem and the Brazilian interconnected power system problem.

4 - Integrating Reinforcement Learning with a Discrete Event Simulation Environment.
Sahil Belsare, Mohammad Dehghani

In recent years, reinforcement learning has seen rapid growth with significant potential in solving sequential decision-making problems. This paper introduces an integrated solution methodology based on reinforcement learning and a discrete event simulation environment. In this approach, simulation allows an agent to interact with a simulated environment and learn the optimal policy. This study uses SimPy, a discrete event simulation library in Python, to model an M/M/C queuing system and apply RL techniques to solve it. Multiple demand scenarios, as well as RL algorithms, are tested to run experiments and provide insightful results.

■ TC-26

Tuesday, 12:30-14:00 - Virtual Room 26

Topics in Nonlinear Optimization

Stream: Nonlinear Optimization
Invited session
Chair: *Michal Kocvara*

1 - Anderson Accelerated Douglas-Rachford Splitting
Anqi Fu, Junzi Zhang, Stephen Boyd

We consider the problem of nonsmooth convex optimization with linear equality constraints, where the objective function is only accessible through its proximal operator. This problem arises in many different fields such as statistical learning, computational imaging, telecommunications, and optimal control. To solve it, we propose an Anderson accelerated Douglas-Rachford splitting (A2DR) algorithm, which we show either globally converges or provides a certificate of infeasibility/unboundedness under very mild conditions. Applied to a block separable objective, A2DR partially decouples so that its steps may be carried out in parallel, yielding an algorithm that is fast and scalable to multiple processors. We describe an open-source implementation and demonstrate its performance on a wide range of examples.

2 - Coordinate descent with greedy coordinate selection for optimization on the orthogonal group
Estelle Massart, Vinayak Abrol

Several machine learning problems involve optimization on the orthogonal group. A typical example is the training of orthogonal deep neural networks, i.e., networks whose weight matrices are constrained to be orthogonal. Projected gradient methods are typically costly for those problems, as re-orthogonalization of the iterate comes with a cost that evolves in a cubic way with the size of the matrix. Riemannian optimization techniques provide alternative feasible algorithms for optimization under orthogonal constraints. In this talk, we explore Riemannian coordinate descent on the orthogonal group. The resulting algorithm works as follows: at each iteration, two columns of the iterate are chosen and rotated in order to decrease the cost; this is equivalent to restricting the update of the iterate to a coordinate vector of the tangent space to the manifold when the latter is equipped with its classical basis. This update rule can be expressed in terms of Givens matrices, and the resulting cost per iteration scales linearly with the size of the matrix. Among others, we address the coordinate selection problem, and propose and compare numerically methods for selecting the coordinates in a greedy way (in line with the well-known Gauss-Southwell rule in the Euclidean setting). We finally present numerical illustrations of the proposed algorithms related to machine learning applications.

3 - Relaxed alternating minimization algorithm for convex optimization problems in image denoising
Yuchao Tang

In this paper, we propose a relaxed alternating minimization algorithm for solving two-block separable convex minimization problems with linear equality constraints, where one block in the objective functions is strongly convex. This algorithm is derived from the relaxed proximal gradient algorithm. We prove that the proposed algorithm converges to an optimal primal-dual solution of the original problem. Furthermore, we study asymptotic $circ(frac1k)$ convergence rate of the primal feasibility residual, where k is the number of iterations. As applications, we apply the proposed algorithm to solve several composite convex minimization problems arising in image denoising and evaluate the numerical performance of the proposed algorithm on a novel image denoising model. Numerical results on both artificial and real noisy images demonstrate the efficiency and effectiveness of the proposed algorithm.

4 - Non-smooth optimization in complex numbers for the ACOPF problem
Antoine Oustry, Leo Liberti, Claudia D'Ambrosio, Jean Maeght, Manuel Ruiz

The Alternating Current Optimal Power Flow (ACOPF) problem is a challenging optimization problem related to the economic dispatching of electricity in a power grid. It is an active research topic, which interests both the power systems and operations research communities. Despite the considerable research on this topic, solving national-scale instances to global optimality is still a challenge. So as to quantify the optimality gap of any solution found with a local optimization algorithm or to implement global branch-and-bound algorithms, it is crucial to compute lower bounds on the value of this Quadratically Constrained Quadratic Programming (QCQP) problem in complex numbers. For this purpose, this paper introduces an original approach to solve the Lagrangian dual of the ACOPF problem, which is also the Hermitian semi-definite programming (SDP) dual problem of the rank relaxation. The proposed reformulation for the dual problem is an unconstrained concave maximization problem involving the maximum eigenvalue of a Hermitian matrix function. To solve this new formulation, we extend the bundle method approach for solving convex optimization problems involving the maximal eigenvalue of a real symmetric matrix function to the case of Hermitian matrix functions. We present promising numerical results on national-scale instances from the MATPOWER Library.

■ TC-27

Tuesday, 12:30-14:00 - Virtual Room 27

Optimization and Learning from Data

Stream: Big Data and Optimization
Invited session
Chair: *Claudia Soares*

1 - An Air Pollution Prediction Pipeline using Measurements of Pollutants Concentrations, Traffic Jams and Atmospheric Conditions with Missing Observations
David Vicente

We present a pipeline designed to predict air pollutants concentrations from various sources of data. In real world applications data is often noisy and some observations are likely to be missing. The proposed pipeline deals with missing data through the means of a low-rank matrix completion method, which is used to impute the missing entries. We then use a semiparametric regression model to make spatial-temporal predictions of pollutants concentrations. This model is designed so that the coefficients of the linear term are inferred from the relationship between pollutants concentrations measurements and traffic jams counts together with measurements of atmospheric conditions, with the resulting residuals being modeled by a nonlinear, nonparametric Multitask Gaussian Process. The resulting model can then be use to predict pollutants concentrations at a physical distance from monitoring stations, predict values in time, or both.

2 - Clustering of the Blendshape Facial Model
Stevo Rackovic

Digital human animation relies on high-quality 3D models of the human face—rigs. A face rig must be accurate and, at the same time, fast to compute. One of the most common rigging models is the blendshape model. We present a novel approach for learning the inverse rig parameters at increased accuracy and decreased computational cost at the same time. It is based on a two fold clustering of the blendshape face model. Our method focuses exclusively on the underlying space of deformation and produces clusters in both the mesh space and the controller space—something that was not investigated in previous literature. This segmentation finds intuitive and meaningful connections between groups of vertices on the face and deformation controls, and further these segments can be observed independently. A separate model for solving the inverse rig problem is then learnt for each segment. Our method is completely unsupervised and highly parallelizable.

3 - Decentralized Learning of a Mixture of Gaussians From a Dataset Distributed by Features
Pedro Valdeira, Claudia Soares, Joao Xavier

We propose a decentralized learning algorithm, GIFT, by which a network of agents learns a mixture of Gaussians from a dataset split across the network by features. Datasets split by features are the hallmark of increasingly many applications, among them online shopping records, online social network interaction (both collected by different providers), teams of robots, IoT, wireless sensor networks, and data silos in between departments within large companies dealing with the same customer base. Assuming an underlying sparse communication network that connects each agent only to a few neighbors, we derive an algorithm that learns a mixture of Gaussians from the full network-wide dataset, without requiring the full dataset to be accumulated in a central node. Further, GIFT allows for a gamut of data sharing options, from no data exchanged between data centers to data sharing within local hubs. Our algorithm is a decentralized form of EM, with proven local convergence, relying on distributed optimization techniques, namely consensus. Finally, we tested the performance of GIFT in typical and limiting scenarios of network topologies for both synthetic and real data. The dataset used in the experiments concerns the overcrowding of emergency departments, the understanding of which is crucial in healthcare management.

4 - Learning to rank from pairwise noisy comparisons, covariate data, and prior knowledge
Claudia Soares

Psychology advocates that humans are better in comparing pairwise elements than a large sets of items. Based on a data model of comparison data, we formulate a nonconvex problem to learn the optimal ranking, including covariate data and, possibly, prior knowledge, and devise a convex relaxation to approximate the solution. We further propose an iterative scheme to optimize the original nonconvex problem. We illustrate the behavior of our method in a real perceptual dataset.

■ TC-28

Tuesday, 12:30-14:00 - Virtual Room 28

The Role of Mathematical Optimization in Data Science I

Stream: Mathematical Optimization and Data Science
Invited session
Chair: *Claudio Gambella*

1 - Introducing the ordered weighted average in the soft-margin SVM
Luisa I. Martínez-Merino, Alfredo Marín, Justo Puerto, Antonio Manuel Rodriguez-Chia

Support vector machines (SVMs) have become one of the most useful mathematical programming approaches for supervised classification. The classical soft-margin SVM model minimizes an objective function given by the inverse of the margin between the supporting hyperplanes and the sum of the deviations of misclassified objects penalized by a parameter.

In this talk, we propose an SVM model where weights are assigned to the sorted values of slack variables associated with the deviations. Thus, we include the ordered weighted average operator in the soft-margin SVM. Unlike other approaches, this is a one-step method where the classical model is adequately modified.

We show that the dual form of the proposed model allows to use a Kernel function in order to construct nonlinear classifiers. Besides, we present some computational results about the predictive performance of the introduced model (also in its Kernel version) in comparison with other SVM models existing in the literature.

2 - Clustering and Interpreting via Mathematical Optimization
Kseniia Kurishchenko, Emilio Carrizosa, Alfredo Marín, Dolores Romero Morales

In this paper, we investigate how to make cluster analysis more interpretable. The goal is to find an explanation for each cluster such that the total true positive cases (i.e., the number of individuals in a cluster that satisfy the explanation chosen for the cluster) is high and the total false positive cases (i.e., the number of individuals outside the cluster that satisfy the explanations chosen for the cluster) is low. We study two types of explanations, namely prototype-based and rule-based, and propose mathematical optimization models for each of them. We illustrate our approach on several well-known datasets with different sizes and types of data.

3 - Learning a reinforcement-learning-based heuristic over graphs for hub location problems
En-Cheng Chang, Deepak Ajwani, Paula Carroll

P-median and p-hub median are combinatorial optimisation problems that are applied to rich real-world problems, such as transportation, telecommunications, etc. As a result, they have been attracting researchers' attention in optimisation and network design domains for decades. These problems have traditionally been solved using exact/approximation algorithms and/or heuristics. However, since these two combinatorial optimisation problems are NP-hard, exact algorithms for them suffer from high computational costs while designing heuristics still requires specialised knowledge and a hand-crafted process. Fortunately, in recent years, there has been a series of research work showing that leveraging reinforcement learning to solve optimisation problems is a promising research direction with potential to automate the design of good heuristics for a given input distribution. Building on this line of work, we explore various combinations of graph representations and reinforcement learning frameworks to learn good heuristics for p-median and p-hub median problems. The set of graph representations include various graph embeddings and carefully hand-crafted features, while the set of reinforcement learning techniques include various value based and policy based methods.

4 - Optimization Problems for Machine Learning: A Survey
Claudio Gambella, Bissan Ghaddar, Joe Naoum-Sawaya

Leveraging data in business decision making is nowadays mainstream as any business in today's economy is instrumented for data collection and analysis. While the aim of machine learning is to generate reliable predictions, management science problems deal with optimal decision making. Thus methodological developments that can leverage data predictions for optimal decision making is an area of research that is critical for future business value. The widespread adoption of machine learning is in parts attributed to the development of efficient solution approaches for the optimization problem of training machine learning models. This work surveys the machine learning literature and presents machine learning as optimization models. Such models can benefit from the advancement of numerical optimization techniques which have already played a distinctive role in several machine learning settings. Particularly, mathematical optimization models are presented for commonly used machine learning approaches for regression, classification, clustering, and deep neural networks as well as new emerging applications in machine teaching and empirical model learning. The strengths and the shortcomings of these models are discussed and potential research directions and open problems are highlighted.

■ TC-29

Tuesday, 12:30-14:00 - Virtual Room 29

AI and Big Data Analytics for Decision Making

Stream: AI and Decision Making
Invited session
Chair: *Fatima Dargam*

1 - Exploiting geospatial large-scale structure for crime prevention
Ben Moews, Jaime Argueta, Antonia Gieschen

Crime prevention tactics are currently in the process of exploring modern computational approaches to police routing and hot spot identification. One dominant issue of current methods is a focus on epicenters identified with coarse-grained density mapping. In order to improve police patrol optimization, we propose multiple extensions of the subspace-constrained mean shift algorithm and apply our approach to crime data from the City of Chicago to extract detailed filamentary density structures as non-linear and mode-following ridges that can be mapped to route template waypoints. We focus on Part I crimes as offense types that society has strong incentives to prevent. We compare our approach to current practices such a kernel density estimations and create multi-run confidence intervals, demonstrating the superior crime coverage in narrow distance envelopes around identified route templates to enhance the efficiency of patrols. Additional tests for the predictive accuracy based on previously identified structure shows the stability of extracted filaments over time. We also discuss the further potential as well as limitations of our approach, and provide an easily accessible Python 3 software package for researchers and practitioners.

2 - Artificial Intelligence Imagery Analysis for Enhanced Decision Making
Stefan Cremer, Claudia Loebbecke

In the era of Artificial Intelligence (AI) and advanced big data analytics, harnessing a considerable volume of unstructured data supports improved decision-making. In particular, Artificial Intelligence Imagery Analysis (AIIA) provides an innovative method for analyzing large pictorial datasets. To this end, we engineer AIIA to meet specific decision needs and employ it to decompose and assess more than 50,000 images in the context of decision making for selling and buying media goods. We find that AIIA profoundly improves decision making over previous methods that mostly relied on humans.

3 - Pros and Cons of Sensor Data for AI-Based Decision Making
Irina Boboschko, Claudia Loebbecke

Technological developments offer new opportunities to improve decision making. Recently, Artificial Intelligence (AI) has gained growing attention in this respect; it builds upon innovative algorithms, AI training data, and decision input data. In this work, we focus on the required data and examine the pros and cons of collecting sensor data for AI-supported decision making. Along three examples, we illustrate both the opportunities as well as the risks of deploying sensor data in AI-based approaches for decision making under uncertainty.

■ TC-30

Tuesday, 12:30-14:00 - Virtual Room 30

OR in renewable energy

Stream: Mixed Integer Linear Programming
Invited session
Chair: *Martina Fischetti*

1 - Mathematical Models to optimal dimensioning and managing battery energy storage for solar photovoltaic system of a multi-apartment building
Lavinia Amorosi, Paolo Dell'Olmo

This talk presents an overview on the main problems for dimensioning and managing battery energy storage for Solar Photovoltaic (PV) system integration and then focuses on a more specific class of problems for residential buildings. The global aim is the maximization of the collective self-consumption controlling the energy sold and bought and the monitoring of batteries state while they range from the minimum to the maximum levels during the time horizon. This is obtained through a mathematical programming model with three different objective functions which can be tuned to find Pareto optimal solutions. The computational results on detailed scenarios with real data validate the model and give a measure of saving of bought and sold energy.

2 - Public Transport-based Crowd-shipping with Backup Transfers
Barış Yıldız, Kerim Uygur Kızıl

With the rising urbanization and booming e-commerce, traditional last-mile delivery systems fail to keep up with the exploding demand and to satisfy the need for faster, cheaper, and more environmentally friendly deliveries. Several new approaches are put forward as an alternative to classical delivery systems in this regard, yet none of them offers the same level of flexibility, capacity, reliability, and managerial control by itself. This paper proposes a new last-mile delivery model that combines several new approaches and technologies to address this issue. More precisely, we suggest using public transit as a backbone network completed by automated service points, crowd-shipping, and backup transfers with zero-emission vehicles to provide a low-cost and environmentally friendly express delivery service. Offering cheap, reliable, and fast transfers between any two locations in an urban area, such a delivery network can provide unique opportunities for small and medium-sized businesses to participate in the e-commerce ecosystem and help large e-tailers to lower their costs and improve service quality. The design problem for the envisioned system is formulated as a two-stage stochastic program, and a branch-and-price (BP) algorithm is devised to solve it. Taking advantage of the nearly decomposable structure that would emerge in possible real-world applications, our study presents the first example of using decomposition branching in a BP framework.

3 - Optimization Models for Installation Planning of Offshore Wind Farms
Martina Fischetti, Lavinia Amorosi, Rosario Paradiso, Roberto Roberti

The increased focus on renewable sources of energy and the increasing competition in the wind energy business have brought new attention to optimization and cost saving initiatives in all the lifetime of wind farms. In this work, in particular, we focus on the optimization of the installation phase of offshore wind farms. This is the task of constructing wind turbines at sea and connecting them through cables. This is a complex task that requires expensive specific vessels and thus involve high costs. These costs need to be considered in addition to revenues from operating the constructed turbines: as soon as a turbine is built and connected to the grid, indeed, it produces energy that is sold to the market. Our goal is to optimize the scheduling and routing of installation vessels taking both immediate costs (such as vessel rental) and production revenues into account. We developed original Mixed Integer Linear Programming models to solve the challenge subject to real-world constraints, as presented by our industrial partner Vattenfall. We also considered uncertainties in the weather forecast and how to generate a schedule that is more robust to weather changes.

4 - Considering turbulence in offshore wind farm layout optimization
David Franz Koza, Davide Cazzaro

Turbulence - the standard deviation of wind speed fluctuations - occurs naturally but also due to objects that disturb the free wind flow. In offshore wind farms, upstream wind turbines cause so-called wake-added turbulence on downstream turbines. Higher levels of turbulence translate into higher fatigue loads on turbine components (such as blades) and result in a reduced lifetime. The IEC 61400 standard, a collection of design requirements for wind turbines, defines a condition to evaluate whether the turbulence experienced by a turbine inside a wind farm is acceptable or not. It uses the so-called Frandsen model to assess turbulence for all turbines inside a wind farm. A common way to ensure feasibility of a wind farm layout with respect to turbulence conditions is the use of a minimum-distance constraint in the layout design phase. This approach, however, is conservative, because it imposes the same minimum distance for all wind directions and turbines, and implicitly limits the maximum number of turbines to place in a given area. We present alternative, less conservative ways of considering turbulence in wind farm layout optimization that explicitly exploit the properties of the Frandsen turbulence model. We test those ideas in a state-of-the-art wind farm layout optimizer, and assess their computational cost as well as their impact on the layout design and performance.

■ TC-31

Tuesday, 12:30-14:00 - Virtual Room 31

Decision Support Systems Applications - 1

Stream: DSS
Invited session
Chair: *Jason Papathanasiou*

1 - Inbound logistics optimization solution for Toyota built on top of DecisionBrain Gene platform

Giulia Burchi, Guillaume Vantroeyen

In this presentation, DecisionBrain will talk about an inbound logistics optimization solution for Toyota, considered a worldwide reference in supply chain management, which resulted in over 10% cost reductions. The project was completed in 8 months, from conception to go-live. This produced a high ROI and a payback time of less than one year.

Toyota wanted to streamline the logistics from its suppliers to its assembly plants, just-in-sequence and just-in-time, targeting a 2% transportation costs reduction. Due to the very high volume of vehicles produced, the inbound logistics planning process, mainly performed manually, was very complex and human-intensive.

DecisionBrain used mathematical models to replicate the planners' decision-making, reducing the planning time from 2.5 days to 1 hour. On top of that, optimization techniques were applied to increase efficiency, reducing transportation costs while preserving service level.

Our solution focused on optimizing the Orders Grouping, Trucks Routing: and 3D packing (matching the package size to each truck's volume).

The fast application development was possible thanks to DecisionBrain Gene (DBGene) platform. DBGene provides an enterprise platform for building and deploying decision support applications. Its main purpose is to facilitate the process of making mathematical optimization available to business users, i.e. bringing optimization decision-making capabilities into the business operation.

2 - Digital Twin in warehousing: A state-of-the-art survey with focus on order picking operation

Anastasios Gialos, Vasileios Zeimpekis

Over the last years the complexity of warehouse operations has increased significantly due to the interaction of numerous parameters in a highly dynamic environment. Especially in order picking operations, the complexity as well as the need for variable picking strategies usually affect in a negative way the performance of the pickers as well as the operational cost. To this end, the development of a decision-making tool which will support order picking operations in an efficient and accurate way in real time, especially in case of unexpected deviations, is of high interest. The development of Internet of Things coupled with computer simulation integration with virtual reality systems and operation data, have formed the basis to address the above necessity via the concept of Digital Twin. The latter creates a mirror of warehouse operations and has the ability to monitor processes in real time and subsequently continuously fine tune all operations in order to improve performance, identify bottlenecks and reduce both mistakes and delays. The aim of this paper is initially to present the state-of-the-art in digital twin concept in warehouse operations. Subsequently, a framework for the development of a Digital Twin decision making tool for the planning and real time monitoring of order picking operations is described. Potential benefits from the implementation of Digital Twin in order picking operations as well as a future research agenda conclude the paper.

3 - Efficient loading and unloading operations via a booking system

Andrea Mor, M. Grazia Speranza, José Viegas

Urban distribution of parcels and goods usually requires vehicles to temporarily stop at roadside to allow for the driver to perform the last leg of the delivery by foot. The stops take place in designated areas, called loading/unloading (L/U) areas, composed of one or more parking spots. In this paper the introduction of a booking system for the management of the L/U areas in a city center is studied as a way to eliminate, or at least substantially reduce, double parking. A booking management system and the related routing problem are presented. In this system, distributors book in sequence according to their preferences and routing constraints, but subject to the bookings that have already been placed. The solution provided by the booking system is discussed and compared with the current use of the L/U areas, where the distributors do not consider the availability of a parking spot and resort to double parking if none is available.

4 - In-Vehicle Personalized Routing for A Heterogeneous Group: An Experience-Based Method for Decision Support System

Özlem Çavuş, Sehnaz Cenani, Gülen Çağdaş

Customized navigation devices allow personalized routings based on user preferences. In determining common preferences for multi-user, it may become difficult to meet at a common point due to conflict of interests. A decision support system could serve as an asset to increase the quality of decisions users take. In conventional systems, decision making ties to pre-defined preferences of a single user or a homogeneous group. Besides, the recommendation of locations ignores the functional use of the space in time. However, decision-making depends on users' experiences within a social group in regard to time and space. Therefore, this study aims to develop a decision support system for a heterogeneous group by involving this neglected side of the design knowledge. This paper proposes a method based on IoT, agent-based modelling, multi-objective optimization, and crowdsourced data. The method is exemplified over a simulation for a family car, including father, mother, and child, to show how the method works. The simulation is created in Grasshopper for Rhino using the addons as Mosquito 0.5a, Firefly, Shortest Walk, and C# script embedded in Grasshopper. The original contribution of this study would reflect itself in showing how social aspects in determining preferences of a heterogeneous group can be converted to a computational environment of personalized navigation systems. The major problem faced with is the data sharing policies.

■ TC-32

Tuesday, 12:30-14:00 - Virtual Room 32

MCDM for project portfolio problems

Stream: Multiple Criteria Decision Analysis
Invited session
Chair: *Maria Barbati*

1 - Multi-period portfolio decision analysis with activities duration: an application in the infrastructure management sector
Gaia Gasparini, Matteo Brunelli, Marius Dan Chiriac

We present an approach to scheduling activities through a defined time horizon where the computational part is coupled with an expert preference elicitation model. Selecting and planning a large number of activities needs to take into account several constraints of a different nature: temporal, economic, and feasibility. Furthermore, activities have to be ranked in order of relevance, from the point of view of the users, and on this basis plan their execution. To address these issues, the model presents elements of portfolio decision analysis and Multi-Attribute Value Theory, with the aim of creating an effective method of activities prioritization, and elaborates a multi-period optimization problem with activities duration. The formulation of the problem is inspired by a real-world infrastructure management case in the energy distribution sector and the whole model is tested on a dataset of more than three hundred activities with different constraints and characteristics. Results are analyzed and robustness and real applicability of the method are studied.

2 - Improving the production quality control adopting a multicriteria decision aiding approach in the automotive sector
Gerarda Fattoruso, Maria Barbati, Massimo Squillante, Alessio Ishizaka

We propose a new multicriteria decision aiding approach to support quality control in automotive plants. Our method is based on two steps. Firstly, adopting a multicriteria decision aiding technique, we classify the errors in priority classes based on a set of criteria in agreement with the management of the company. In particular, we adopt the AHPSort II method that allows considering a variety of criteria and a large number of errors, while interacting with the management of the company. Secondly, we define a multiobjective portfolio problem that selects a portfolio of most critical processes on the basis of the number of errors happening in each of these processes. We adopt an interactive method for finding the most preferred portfolio of processes according to the preferences of the stakeholders. We applied our approach in an automotive plant in the South of Italy.

3 - Interactive multiobjective space time optimization models for urban planning
Simona Panaro, Maria Barbati, Salvatore Greco

We propose a new methodology for supporting urban planning. Our approach is based on a multiobjective space-time optimization model that supports the decision-maker in the construction of the most preferred plan step by step. Our approach permits to take into account preferences expressed by stakeholders and suggestions provided by experts along the decision process. Moreover, our approach permits to take into account several requirements of different nature such as budget constraints, environmental concerns, or architecture specifications. The salient characteristic of our approach is the continuous interaction between the users and the decision support model.

4 - A new model for multiobjective portfolio selection problems
Maria Barbati, Salvatore Greco, José Rui Figueira

We consider a portfolio decision model in which both the portfolio of projects and the portfolios themselves need to be selected. More in detail, our model selects the portfolios of projects on the basis of strategic objectives and on the basis of the portfolios of elements allocated to each project. In particular, a project can be selected and, therefore, contributing to the objectives to optimise, only if the elements selected are appropriately contributing to some criteria. Indeed, we assume that elements that are included in these portfolios are evaluated on the basis of some criteria not necessarily of the quantitative type. We show through some didactic examples how the model works and we propose an interactive methodology to handle the problem.

■ TC-33

Tuesday, 12:30-14:00 - Virtual Room 33

Business Analytics I

Stream: Business Analytics
Invited session
Chair: *Kristof Coussement*
Chair: *Philipp Borchert*

1 - Investigating the beneficial impact of the logit leaf model for credit scoring
Khaoula Idbenjra, Kristof Coussement, Arno De Caigny

Despite the advances of the machine learning field, most of the prediction models lack interpretability, which is crucial in several applications like for instance in credit scoring. Therefore, the simplistic logistic regression remains the golden standard in the credit scoring field, mainly because it combines good predictive performance with simplicity and transparency in its predictions. In this study, we introduce the Logit Leaf Model (LLM) as an alternative credit scoring algorithm. The LLM is a hybrid segmentation-based model that aims to improve the predictive power of the logistic regression model by segmenting the initial customer population, while keeping the model easily interpretable. The experimentation benchmarks the LLM method against the logistic regression and other various state-of-the-art classification techniques. The preliminary results are promising with respect to the predictive performance and interpretability of the proposed method.[U+202F][U+202F]

2 - Actionable Knowledge Discovery and Rule Mining in B2B Churn
Emil Guliyev, Kristof Coussement, Arno De Caigny

B2B enterprises seek to cultivate long-term relationship with customers which highly depends on customer engagement and trust building. The application of attrition models can be helpful to measure the health of business relationship and reduce churn by applying proactive targeting strategies on potential churners. Even if existing churn models help to identify such customers, the results don't provide an actionable solution for firms with proactive strategies and it often requires additional step to define preventive remedies on those potential churners. It is gaining more popularity among academic researchers that the paradigm shift from data-driven to domain-driven approach could close this gap between the discovery of knowledge from data and the needs of business domain. Actionable Knowledge Discovery is one the concepts that converts the knowledge into the concrete actions and helps firms in better decisions making. Some researchers have studied that Action Rule Mining models not only produce the probability of churn, but also suggests set of churn preventions actions. Even if these concepts are introduced in the literature, there is a lack of field tests in real-world B2B environment. This novel study tests the potential implications of action rule mining in B2B churn context and compares it to traditional churn models. Our results suggest that building actionable churn models could bring more value to enterprises by providing direct intervention actions.

3 - A deep learning model for cross-selling recommendations in the financial service sector
Stephanie Beyer Diaz, Kristof Coussement, Arno De Caigny

Cross-selling has become essential for customer relationship management, as it can help a company improve the relationship with its customers, increase the customer lifetime value and reduce the churn rate. To facilitate successful cross-selling, it is important to get ahead of a customers' needs. For this, recommender systems can be used to transform user preferences into predictions of their likes, needs and interests. This may in turn improve customer satisfaction and loyalty. Thus, the objective of this paper is to contribute to the research of recommender systems in the financial services sector. The contributions are the evaluation of deep learning techniques against state-of-the-art recommender approaches. The study uses monthly data obtained from an international financial services provider, used as input for the deep learning models. The results are compared using a cross-validated F1 measure and G-mean. A statistical comparison between the best performing approaches is carried out to confirm the results are generalizable. The study also provides important recommendations for financial services providers, specifically regarding method effectiveness, time horizon depth, and model optimization. The data used consists of 788,141 customers and 22 different products, with variables aggregated on a monthly basis. To the best of our knowledge, our study is the first to evaluate deep learning models performance as recommender systems in the financial service sector.

4 - BusinessBERT - A pre-trained language model for finance and business related text
Philipp Borchert, Jochen De Weerdt, Kristof Coussement, Arno De Caigny

With a large body of research dedicated to natural language processing (NLP), recent studies showcase the added value of pre-trained general-purpose language models like Bidirectional Encoders from Transformers (BERT) across multiple domains. Depending on the field of study, the application of general-purpose models requires extensive fine-tuning steps, due to the shift of word distribution and specialized vocabulary. By transferring the BERT architecture on domain specific text, related research achieved significant performance improvements in the scientific, biomedical and law domain. However, the literature investigating the application of pre-trained BERT models for the financial and business is very scarce. This study introduces BusinessBERT, a pre-trained language model for financial and business related text. The model is trained on three large-scale corpora, in order to cover a wide range of textual data sources used in financial NLP applications. We extracted text from 656 586 company websites (0.3 billion words), including small and medium sized enterprises as well as large enterprises. Additionally, we used textual content extracted from scientific literature in the business domain (0.65 billion words), as well as the management discussion and analysis section included in 10-K disclosures (0.95 billion words) to train BusinessBERT. We benchmark the performance on multiple datasets, containing classification as well as named entity recognition (NER) tasks.

■ TC-34

Tuesday, 12:30-14:00 - Virtual Room 34

Optimization Topics in Sustainable Logistics

Stream: Combinatorial Optimization
Invited session
Chair: *Erwin Pesch*
Chair: *Alena Otto*
Chair: *Nora Dörmann*

1 - Eco-Labeling in Stochastic Dynamic Multimodal Transportation
Arne Heinold, Frank Meisel, Marlin Wolf Ulmer

Eco-labels state a maximal amount of greenhouse gas emissions to be emitted while transporting orders from their origins to their destinations. In contrast to other eco labels, e.g., for household appliances, ensuring satisfaction of eco-labels is more challenging for multimodal, long-haul transportation problems due to consolidation effects with other (potentially yet unknown) orders and capacity restrictions of the fleets.

In this work, we analyze the impact of eco-labels for such a multimodal long-haul network. Orders are uncertain in terms of the point in time in which they appear, their origin and destination, and their associated eco-label. Whenever new orders occur, decisions are made about the mode of transportation, consolidated via high-capacity vehicle or direct via truck.

We model the stochastic dynamic problem as a multi-objective Markov Decision Process and solve it via value function approximation, a method of reinforcement learning. Our approach aggregates states based on features specific to eco-labeling. We compare our method to a perfect information case and a rolling horizon procedure on data from a TEN-T core corridor. We can show that there are substantial differences in the routing plan for the obtained pareto solutions. Further, a careful fit of the value function is required as orders' eco-labels make it difficult to follow simple solution policies.

2 - A modelling and algorithmic framework for integrating long-haul transshipment and local transportation
Stephen Maher, Junko Hosoda, Yuji Shinano, Jonas Christoffer Villumsen

Supply chain management comprises many vehicle routing and scheduling problems across different time and geographical scales. In this talk, we discuss a supply chain management problem spanning a large geographical area that integrates customer clustering, transshipment and local transportation. While much research has been performed on each component of our proposed problem, there is currently no established technique for the integration of transshipment with local transportation. This talk will present an iterative, large-neighbourhood search heuristic to find high quality solutions to the integrated transshipment and local transportation problem. We will describe the numerous techniques necessary to diversify the search and solve large-scale supply chain management problems. Our proposed heuristic is able to find high-quality solutions for the integrated problem that significantly reduce costs compared to solving each problem sequentially.

3 - On the influence of collection cost on reverse channel configuration
Nora Dörmann, Jochen Gönsch

This talk revisits the impact of collection cost on a manufacturer's optimal reverse channel choice and complements previous research by Savaskan et al. (Savaskan RC, Bhattachary S, Van Wassenhove LN (2004) Closed-loop supply chain models with product remanufacturing. Management Science 50(2): 239-252) and Atasu et al. (Atasu A, Toktay LB, Van Wassenhove LN (2013): How collection cost structure drives a manufacturer's reverse channel choice. Production and Operations Management 22(5): 1089-1102.). A manufacturer who remanufactures his own products has the choice between managing collection of used products himself, let the retailer manage collection or involve a third party company to manage collection. In a stylized model, we consider a convex collection cost function depending on the collection rate. Contrary to previous literature, we analytically show that the manufacturer always prefers retailer-managed collection, independent of collection cost. The retailer will always choose a positive collection rate. If collection cost is above a certain threshold, not all used products will be collected and the manufacturer (almost) collects all channel profits. Third party-managed collection is always dominated. In extensions, we also consider a restriction to equilibria and a minimum collection rate, which may be imposed by regulation.

4 - A covering tour approach and a two-phased heuristic method for the location of waste collection sites
Meritxell Pacheco Paneque, Vera Fischer, Antoine Legrain, Reinhard Bürgy

In waste collection, a curbside system is widely applied and causes high fuel consumption, emissions and noise. These effects can be mitigated by requesting residents to bring their waste to collection sites in their neighborhood such that trucks stop at fewer locations while ensuring that all waste is being collected. We refer to this optimization problem as the capacitated multi-vehicle covering tour problem on a road network (Cm-CTP-R). We develop two compact mixed-integer linear programming formulations: a road network-based formulation that exploits the sparsity of the network and a customer-based formulation typically used in vehicle routing problems. We propose a two-phased heuristic approach that first addresses a set covering problem to select the stopping locations that can cover the residential buildings and then a capacitated vehicle routing problem to determine the routes. To create efficient tours, we introduce the idea of alternatives to given stopping locations which can cover the same residential buildings. We apply selected local search procedures in both subproblems. Computational experiments on real-life instances (more than 1000 nodes) show that the road network-based formulation is better suited. Furthermore, the proposed heuristic quickly provides good solutions and confirms the implementation of alternative locations and local search procedures.

■ TC-35

Tuesday, 12:30-14:00 - Virtual Room 35

New tools in Insurance

Stream: Actuarial modeling and risk management
Invited session
Chair: *Massimiliano Menzietti*

1 - Mixed participating and unit-linked life insurance contracts: design, pricing and optimal strategy
Vanessa Hanna

In many countries, the decline in interest rates has reduced the interest in traditional participating life insurance contracts with investment guarantees and has led to a shift to unit-linked policies without guarantees. We design a novel mixed insurance contract splitting premium payments between a participating and a unit-linked fund. An additional guarantee fee is applied on the unit-linked return in order to increase the investment guarantee of the participating fund. In a utility-based framework, using power utility and prospect theory as preference functions, we show that the mixed product is usually perceived more attractive than a full investment in either the unit-linked or the participating contract. The guarantee fee is beneficial for conservative investors interested in a stronger protection against losses. This is also interesting from a marketing perspective: By the increase of the guarantee in the participating product, zero or negative guaranteed rates can be avoided.

2 - Optimal Retirement with Long-Run Income Risk
Seyoung Park, Shan Huang

Standard retirement literature fails to explain the empirical evidence that stock investment increases with retirement age, i.e., individuals who retire early invest less in the stock market. We explain this evidence via two economic channels. First, the portfolio share rises with wealth in the presence of long-run income risk modeled by cointegration between the stock and labor markets. Those retiring early have less wealth and hence, find it optimal to invest less in the stock market. Second, retirement flexibility itself makes the optimal portfolio invest less in the stock market with the long-run income risk. The flexibility of supplying labor for a longer time rather exposes individuals to the greater income risk in the long run, reducing the stock investment.

3 - Optimal cash back allocation in Peer to Peer Insurance
Susanna Levantesi, Gian Paolo Clemente, Gabriella Piscopo

This work focuses on peer-to-peer insurance (P2P), through which a group of participants share risks and benefits. Digital technology is used to connect participants. In a typical broker model, the members of the group in a P2P insurance scheme share the first layer of their cumulative losses, while the higher layer is transferred to a third party. In order to enter the mutual group, each participant has to pay an initial contribution based on a sharing risk rule, that has to be intuitive and transparent. According to the most considered conditional mean risk-sharing rule, the participant has to initially contribute with an amount equal to the expected value of the risk he brings to the pool given the total loss distribution. The excess of total contributions net of total realized losses is distributed to participants as cashback. In this work, we propose a different way to share the cashback in a cooperative game, applying the concept of Shapley value and optimizing the allocation of the remaining capital.

4 - Weather parametric insurance in agricultural risk management
Marco Pirra, Massimiliano Menzietti

The increase in the frequency and severity of extreme weather events (droughts, storms and others) associated with climate changes has relevant impacts for European agriculture and reduces livelihood options for millions of small-scale farmers in low-income countries. Weather parametric insurance schemes are a possible option in managing weather and climate risks because they refer to weather station data or grid data (rainfall, temperature) in order to assess the payouts and these are therefore immediate and with fewer disputes than conventional crop insurance coverages. These insurance schemes are at a developmental stage but can be considered an attractive opportunity, due to their advantages: low costs, no information asymmetry, abundant data, wide spectrum of activities covered, flexibility. The goal of the study is to investigate the potential benefits that the improvement in the design of insurance solutions (and the predictive analytics techniques) could offer in this area, reducing the underwriting inefficiencies, developing better insurance products and improving sustainable strategies to make agricultural sector more resilient.

■ TC-36

Tuesday, 12:30-14:00 - Virtual Room 36

Dynamical Models in Sustainable Development II

Stream: Dynamical Models in Sustainable Development
Invited session
Chair: *Veronika Smejkalová*

1 - Analysis of Success in a Business, Systems Thinking Applied
Håkon Veddegjerde, Mo Mansouri

A business or an organization can be viewed as a system. Is this system complex, and is it possible to understand the structural composition of the complexity by applying systems thinking? This paper will evaluate a business as a complex system, and its evolution with the perspective of success or failure. In addition, evaluating systemic forces, agents, causalities, and other elements in an effort to minimize the risk of failure.

2 - Applying Agent-based Simulation for scheduling robust First/Last Mile Microtransit Services in Rural Environments
Christian Truden, Martin Kollingbaum

We investigate sustainable and reliable forms of rural passenger mobility. Individual transportation and vehicle ownership is the main form of transportation in rural areas, as these areas suffer from insufficient provisions of public transportation. Individual car use is, however, a main producer of carbon emissions. Transport services are primarily required by commuters and pupils that need transport to urban centers. We propose features for the implementation of transport systems that support shared travel for various purposes, such as commuting, daily errands, or visits to a physician. Our approach complements existing public transport systems and may serve as a feeder system. We combine large neighborhood search with agent-based modelling and simulation to generate transport schedules (according to objectives such as minimizing carbon emissions) for microtransit services and validate them in terms of vulnerability to delays of passengers or vehicles, and acceptance rates of ad-hoc requests. Passengers, vehicles, and elements of the transport network (stops) are modelled as agents. We study how disturbances, such as delayed services or tardiness of passengers, affect the stability of a transport schedule with respect to transfers at stops and the limited passenger capacities of the vehicles.

3 - Optimization techniques in waste quantity predictions
Veronika Smejkalová

Estimates of future municipal waste production will enable more efficient infrastructure development (processing, collection network, transport). As variables that can reliably explain the amount of waste are not known for the future, and their predictions are complex, time series modelling is usually used. Historical waste data include considerable variability and several errors. However, optimization methods can refine waste quantity estimates when certain binding constraints are employed. This paper outlines the possibilities of such modelling, where the relationships between individual types of waste will be defined together with territorial and aggregated hierarchical equations. Approaches based on mathematical programming made it possible to cleanse historical data and estimate future production of individual types of waste.

■ TC-37

Tuesday, 12:30-14:00 - Virtual Room 37

Ethics, health, medicine and food

Stream: Ethics in OR
Invited session
Chair: *R Kazakov*

1 - The impact of External Reference Pricing on the health care system: a hybrid simulation exploration of equitable drug access, affordability and availability
R Kazakov, Susan Howick, Alec Morton

External reference pricing (ERP) regulation and its effects on equitable drug access, affordability and availability in the EU are explored using a hybrid scenario simulator. Two main counteracting behaviors are highlighted: one is connected to the goal of drug price regulators in using ERP to control medicine prices, while the other is connected to the drug suppliers counter behaviour to exploit or avoid the price regulation rules. This tactical game could result in undermining key health care objectives to provide equitable and affordable drug therapies to patients due to drug market entry delays, drug market exits or propagation of excessive drug pricing. The authors have developed a hybrid agent based and system dynamics scenario simulator to explore the effects of the ERP regulation. The construction of the hybrid simulation model was supported by the use of Resource Agent Maps, a novel qualitative modelling technique designed to analyse the interactive behaviour of agents and resources in a complex adaptive systems environment. The simulation results demonstrate that the intention of the ERP regulation to provide affordable medicine prices results in the counter effect of drugs overpricing or drugs unavailability. This brings forward to health care public agenda the question of how to maintain a balance between affordability and availability, and the challenge how to improve drug pricing regulation, in order to resolve this ethical problem and achieve balance.

2 - Interventions on the French wheat-to-bread food value chain and their effects on equitable value distribution: insights from a policy scenario simulator
Seán McGarraghy, Rossen Kazakov, Elise.huber@iddri.org Elise.huber@iddri.org, William Loveluck, Mircea Gherasim, Cosmin Ailoaie, Pierremarie.aubert@iddri.org Pierremarie.aubert@iddri.org

This paper reports on the problem of procedural and distributional fairness along the French wheat-to-bread food value chain and the specific hybrid approach of qualitative and quantitative modelling and simulation which was undertook to address the above issue from the perspective of socioeconomic sustainability of the supply chain system. The paper illustrates how techniques like cognitive mapping and agent resource mapping are used for system analysis, resource flows and agent rules definition. Secondly, we explore how these maps are transferred into a policy scenario simulator for policy experimentation and optional recommendations. This work is part of an EU-funded project focused on understanding European food value chains. Food value chain systems are viewed as complex adaptive systems emerging out of market agents' interactions, resource flows and market price setting. The goal of this hybrid agent modelling approach is to experiment and test various what-if policy and market interventions and to inform the development of transition pathways towards more environmentally sustainable and socially fair food value chains. This paper and the proposed scenario simulator include insights about food value chain actors' behaviour, the factors that influence actors' decisions connected to changes in supply and demand, the interactions among themselves and with the environment, and the factors influencing fair interrelations and fair value distribution.

3 - Simulation exploration of the North Italian tomato food value chain from the perspective of equitable relations and value distribution among market actors
Gianandrea Esposito, Rossen Kazakov, Antonella Samoggia, Seán McGarraghy

Food value chain systems are viewed as complex adaptive systems emerging out of market agents' interactions and market price regulation; Managing such systems is explored through the stages of mapping their behaviour and then simulation of intervention scenarios. This work is part of an EU-funded project on understanding food value chains. We report on initial work on developing a qualitative food system model of the North Italian region tomato value chain market, applying a complex adaptive systems perspective. The paper focusses on the problem of fairness related to price setting and price distribution, and illustrates how techniques like cognitive mapping and agent behaviour mapping are used for system analysis and agent rules definition. The goal of this qualitative agent modelling approach is to support the conceptual, functional and technical specification for the quantitative modelling phase. This paper explores further how a value chain actor (agent) will behave in practice, what actors are there in a particular value chain, what influences their decisions (prices, regulations, etc), what are their interactions among themselves and with the environment, what are the factors influencing fair interrelations and fair value distribution, what are possible scenarios for public policy interventions in regards to improving the system from a more sustainable and ethic perspective? Included are preliminary results, considering simulation potential and limitations.

4 - IMPACT OF ETHICAL BUSINESS PRACTICES ON ORGANISATIONAL COMPETITIVENESS - A Study on Service Sector in India
Rohit Kanda, Harish Handa, Pushpkant Shakdwipee, Jasveen Kaur, Gunmala Suri, G. S. Bhalla, Savita Gautam, Narendra Dashora

The Dissertation held from above study is that Regions with lesser Development in General, in terms of Business, Infrastructure and Economic Development and Lower or Negligible Development in Particular, in terms of Service Sector have more Significance in Existence of Ethical Business Practices, as well as have a Strong Belief that Ethical Business Practices have Positive Impacts on Business Growth & Organisational Competitiveness. Exceptions to the Above Statement are Duly Acknowledged in the Detailed Analysis of Study. The Hypothesis reconfirms to the Empirically proved statement that "ethical practices in business help to create favorable relationships with other organizations and establish long-term positive relationships with existing and potential future customers". Hence, It is recommended for especially for the sampled start-up segment in service sector that "Companies must adopt and disseminate a written Code of Ethics, build a company tradition of ethical behavior, and hold its people fully responsible for observing ethical and legal guidelines to become able to innovate new solutions and values in a socially responsible way, are most likely to succeed (Labbai, 2013). A further research on Asian Perspectives on Growth and Scenario of Services may be an Eye Opener.

■ TC-38

Tuesday, 12:30-14:00 - Virtual Room 38

Dynamical Systems and Mathematical Modelling in OR 3

Stream: Dynamical Systems and Mathematical Modeling in OR
Invited session
Chair: *Katsunori Ano*
Chair: *Sigifredo Laengle*

1 - Non-continuous inputs-outputs variables in DEA for the estimation of knowledge generation and innovation efficiency: the case of CIS
Georgios Koutsouradis, Kostas Tsekouras

Estimation of the efficiency of knowledge generation process, in the context of knowledge production functions (Griliches, 1979) is often hindered by the non-continuity of the input and output variables which are considered in frontiers non-parametric approaches. Using Community Innovation Survey (CIS) microdata, crucial information, such as patents, other forms of Intellectual Property Rights and the introduction of several types of innovation is of binary type and does not allow for the estimation of knowledge generation and innovation efficiency. We develop an analytical methodological context which facilitates the inclusion of knowledge and innovation discrete input and output variables in a Data Envelopment Analysis (DEA) framework which is used to evaluate the efficiency of resources devoted to knowledge and innovation processes (KIP). We take advantage and further develop the analytical approach of Banker and Morey (1986) and Kamakura (1992). We introduce the necessary handling of information provided by the CIS microdata in non-parametric knowledge and innovation frontiers estimation. We employ an input oriented Variable Returns to Scale non-parametric frontier of DEA type. The methodological idea is developed on the imposition of legitimate and reasonable hierarchical structures on the non-continuous knowledge and innovation inputs and outputs. The methodological approach is tested employing the 2012-2014 wave of CIS microdata for Greece, Portugal and Spain.

2 - Satisfying Instead of Optimising Solutions in Business Planning
Sigifredo Laengle

For years mathematical optimisation techniques have been studied and extended to support business planning activities. However, practical decisions rarely coincide with the ones suggested by the results of optimisation models. The question that immediately arises is how to support the decision-maker with suggestions that ensure a set of satisfactory states that are not necessarily optimal? Viability theory (VT) is a mathematical theory that tries to find answers to this question. In particular, VT tries to find a set of satisfactory states of dynamical systems such that at least one trajectory remains within the viable limits. The purpose of this article is to apply the theory to some classic long-term planning problems. Doing this work, we conclude that VT can help the business administrator to identify viable solutions that also include optimal solutions. Finally, we think that further research may extend this work in three directions: investigate effective numerical methods to solve these problems, consider imperfect information phenomena, and develop Decision Support Systems based on VT.

3 - Consistent conjectural variations as optimal Nash strategies
José Guadalupe Flores Muñiz, Viacheslav Kalashnikov, Nataliya Kalashnykova

In general, the concept of consistent conjectural variations for oligopoly models is different from the Cournot-Nash conjecture, however, if we consider the conjectural variations as the possible strategies in a non-cooperative game (named the meta-game), we find an interesting relationship. Define the meta-game as such where the players are the same agents as in the original oligopoly but now using the conjectural variations as their strategies. Then, the Cournot-Nash equilibrium in the meta-game generates the consistent conjectural variations equilibrium for the original oligopoly, moreover, under contain conditions, the inverse is also true, i.e., the consistent conjectural variations equilibrium provides the optimal Cournot-Nash strategies for the meta-game. This equivalence allows us to extend the concept of consistent conjectural variations to other kinds of economic and financial models lacking the oligopoly structure.

■ TC-39

Tuesday, 12:30-14:00 - Virtual Room 39

Planning, scheduling and routing with exact methods

Stream: Routing, Logistics, Location and Freight Transportation
Invited session
Chair: *Ivona Gjeroska*

1 - An exact method for the Multi-Trip Batch Delivery Problem
Alexis Robbes, Yannick Kergosien, Jean-Charles Billaut

We consider a Multi-Trip Batch Delivery Problem: we have a set of batches, each batch is composed of a predefined set of products and each product has to be delivered at a specific location before a given due date. A set of vehicles is carrying out deliveries, batch by batch. They leave from a common depot, deliver all products of their batch and come back to the depot to take charge of the next batch. The problem consists of assigning the batches to vehicles, determining the routes associated with each batch, and minimizing the total tardiness. This problem can be seen as a variant of a Multi-trip Vehicle Routing Problem with soft due dates. We also assume that each batch is associated with a release date (date from which the products of a batch are ready to leave the depot) and the delivery batch sequence of each vehicle is sorted in increasing order of release dates. This study is motivated by real-world applications where the delivery problem takes into account the production stage and the batch composition is imposed. To solve the problem, we propose an exact method based on a tree exploration in three phases. The method uses branch-and-bound algorithm technics with upper/lower bounds, dominance properties, symmetry cuts, and external memory.

2 - Formation, Scheduling and Routing of Worker Teams for Airport Ground Handling Operations
Giacomo Dall'Olio, Rainer Kolisch

We address the optimization of the ground handling procedures at airports, focusing on baggage loading and unloading. Teams of qualified workers have to be formed, scheduled, and routed across the apron to unload the baggage from the aircraft after a landing and to load it before take-off. Such tasks must be performed within time windows and require a number of workers with hierarchical skill levels. The processing time of some tasks can be reduced by assigning more workers. The arising problem consists of a variation of the workforce scheduling and routing problem incorporating team formation, multiple trips, different execution modes, and hierarchical skill levels with downgrading. We propose a decomposition model based on column generation.

In the pricing problem, we generate tours of teams leaving from the depot, performing one or more tasks, and returning to the depot. We model the pricing problem as a resource-constrained shortest path and solve it with dynamic programming. In the master problem, we consider workers on an aggregated level and we select a number of tours such that all tasks are covered. We aim for optimal integer solutions using Branch-and-Bound. We tested our algorithm on instances based on real-world data from a major European hub airport. The results show that the approach finds optimal solutions or suboptimal solutions with low optimality gaps within a short time.

3 - New formulation and solution algorithm for the Strategic Berth Template Problem

Manuel Munoz-Marquez, Elena Fernandez

The Strategic Berth Template Problem (SBTP) aims at deciding which calling ships should be accepted for berthing, and determines the most appropriate berth/time allocation for the accepted incoming traffic. Specifically, its is to develop a template for the accepted ships for a cyclic time horizon. In addition to the limited number of available berths, such a template must take into account that service to a ship may start in the next cycle to the one when it arrives at the port, or that, even if service starts in the same cycle when the ship arrives, its service may terminate in the next cycle. The objective is to minimize the waiting times of the accepted ships plus a penalty for each rejected call.

We develop a new mixed-integer linear programming (MILP) formulation for the SBTP, with binary decision variables that avoid linking explicitly served ships with the berths they are allocated to. Instead, we relate served ships with their immediate predecessor in the corresponding berths. This reduces the number of binary decision variables and the high symmetry that appears when decision variables associate ships with berths. The new formulation is reinforced with the addition of another set of indicator decision variables for the starting service times.

Numerical results from computational experiments with benchmark instances are presented and analyzed. The results show its good performance, particularly in terms of the quality of the lower bounds that it produces.

4 - A two-stage multi-period vehicle routing problem with depot location

Ivona Gjeroska, Sergio García Quiles

We consider a case where a set of customers needs to be visited by one seller and one truck at some point over the planning horizon. The starting and ending depots are different for the set of sellers; while the ending depot is fixed, the starting depot is to be located in each period of the planning horizon. The depot location has no underlying cost. An interesting application for this variation of the multi-period vehicle routing problem originated in a distribution company. The set of sellers is routed from the optimal starting depot in one period of the planning horizon, and a separate set of trucks is routed over the same subset of customers in the next period of the horizon. The trucks begin and end their respective routes from the same fixed depot. The objectives are to minimise the routing costs for the sellers and the trucks, while balancing the workload of both. The problem is modelled as an ILP and solved by means of a branch-and-cut approach. The depot locations for the sellers for every period of the planning horizon, as well as the routes for both the sellers and the trucks are considered as decision variables. The well-known capacity constraints are reformulated as workload constraints and added in the form of cutting planes inside the branching tree. These are identified using a separation algorithm that is later altered to identify cuts that tighten the polytope.

■ TC-40

Tuesday, 12:30-14:00 - Virtual Room 40

Algorithms for shop scheduling problems

Stream: Scheduling and Project Management
Invited session
Chair: *Laurent Houssin*
Chair: *Pierre Lopez*

1 - Scheduling Jobs in Flexible Flow Shops with s-batching Machines

Lars Moench, Jens Rocholl

A scheduling problem for a two-stage flexible flow shop with s-batching machines is considered. A batch is a group of jobs that are processed at the same time on a single machine. A maximum batch size is given. The jobs belong to incompatible families. Only jobs of the same family can be batched together. Setup times occur between different batches. The processing time of a batch is the sum of the processing times of the jobs forming the batch, i.e., the jobs are sequentially processed. Batch availability is assumed. Each job has a weight, a due date, and a release date. The performance measure of interest is the total weighted tardiness. A mixed integer linear program is established. A decomposition heuristic is proposed that uses a grouping genetic algorithm to solve the single-stage subproblems. Moreover, an iterated local search scheme is designed. Results of computational experiments based on randomly generated problem instances are reported.

2 - A branch-and-bound approach for the two-machine flow shop stochastic scheduling problem to minimize the value-at-risk

Lei Liu, Marcello Urgo

Stochastic scheduling addresses scheduling problems involving random attributes and aims at devising schedules which can hedge against the impact of uncertain events within the manufacturing process. We present a branch and bound approach to solve the two-machine permutation flow shop scheduling problem with stochastic processing times. The objective is the minimisation of the value-at-risk of the makespan, to support decision makers in the tradeoff between the expected performance and the mitigation of the impact of extreme scenarios. A Markovian Activity Network (MAN) approach is adopted to estimate the distribution of the makespan and assess the value-at-risk of both partial and complete schedules. The efficiency of the branch and bound algorithm is demonstrated through computational experiments on small and medium size instances, i.e., up to 30 jobs. In addition, instances difficult to solve are further investigated. The benefits of the proposed risk-based scheduling approach are illustrated through a comparison with alternative criteria such as the minimax regret.

3 - Balancing the average completion times of two sets of jobs in a single-machine scheduling problem by Lagrangian relaxation

Antonio Fuduli, Matteo Avolio

We propose a Lagrangian heuristic approach for balancing the average completion times of two sets of jobs. This kind of problems can be interpreted as a two-agent scheduling problem of the cooperative type, in contraposition to the standard competitive multiagent problems where each class of job contributes only to the objective function of its agent. Starting from a nonsmooth variant of the well-known assignment problem and applying a linearization technique, we obtain a mixed integer linear program, characterized by a large number of constraints, for which we propose a Lagrangian relaxation approach that reduces to solve a finite number of successive linear assignment problems. Numerical results on some randomly generated test problems are presented.

■ TC-41

Tuesday, 12:30-14:00 - Virtual Room 41

Public Transport Timetabling

Stream: Timetabling and public transport
Invited session
Chair: *Rolf Van Lieshout*

1 - Integrated Periodic Timetabling and Vehicle Circulation Scheduling
Rolf Van Lieshout

Periodic timetabling is one of the most well researched problems in the public transport optimization literature. However, the impact timetabling has on the number of required vehicles, which directly translates to operator costs, is rarely considered. Therefore, in this paper, we consider the problem of jointly optimizing the timetable and the vehicle circulation schedule, which specifies the cyclic sequences of trips vehicles perform. In order to obtain high-quality solutions to realistic instances, we improve an earlier proposed formulation by contraction techniques, three new valid inequalities and symmetry-breaking constraints. Ultimately, this allows us to explore the trade-off between the number of vehicles and the attractiveness of the timetable from the passengers' perspective. An extensive computational study demonstrates the effectiveness of the improved formulation. Moreover, using this approach we are able to find timetables requiring substantially fewer vehicles at the cost of minimal increases of the average travel time of passengers.

2 - An iterative heuristic for passenger-centric train timetabling with integrated adaption times
Marie Schmidt, Gert-Jaap Polinder, Valentina Cacchiani, Dennis Huisman

We present a method to construct a periodic timetable that is feasible with respect to infrastructure constraints and minimizes average perceived passenger travel time. In addition to in-train and transfer times, our notion of perceived passenger time includes the adaption time (waiting time at the origin station). Adaption time minimization allows us to avoid strict frequency regularity constraints and, at the same time, to ensure regular connections between passengers' origins and destinations. We propose a heuristic approach consisting of two phases that are executed iteratively. First, we solve a mixed-integer linear program to determine an ideal timetable that minimizes the average perceived passenger travel time but neglects infrastructure constraints. Then, a Lagrangian-based heuristic makes the timetable feasible with respect to infrastructure constraints by modifying train departure and arrival times as little as possible. The obtained feasible timetable is then evaluated to compute the resulting average perceived passenger travel time, and a feedback is sent to the Lagrangian-based heuristic so as to possibly improve the obtained timetable from the passenger perspective, while still respecting infrastructure constraints. We illustrate the proposed iterative heuristic approach on real-life instances of Netherlands Railways showing that it finds a feasible timetable very close to the ideal one.

3 - Splitting is Flipping: The Split Closure of Periodic Timetabling Polytopes
Niels Lindner, Berenike Masing

Split inequalities, or equivalently, mixed integer rounding inequalities, are a popular source for general-purpose cutting planes when solving mixed integer linear programs. Collecting all valid split inequalities results in a polyhedron, called the split closure. We investigate the split closure for the Periodic Event Scheduling Problem (PESP), the standard mathematical model for periodic timetable optimization in public transport. It turns out that the split closure is identical to the recently introduced flip polytope. In particular, every facet arises by moving around the well-known change-cycle inequality for some simple cycle and reversing some arc orientations. This endows the split closure with a simple combinatorial description, and conversely, we find that the flip polytope is the natural outcome of a general computational technique.

4 - Timetable adjustment for rail maintenance possessions: from theory to practice
Gabor Maroti

Railway timetables are designed to provide the best possible service on the entirely available infrastructure. However, preventive maintenance works are necessary in order to ensure safe and smooth traffic. Track maintenance is scheduled several months before actually carrying it out, and renders the nominal timetable infeasible.

This research considers large-scale maintenance works that affect an entire day. We are looking for an adjusted timetable that minimises the deviation from the nominal timetable. We compute a 1-hour timetable as our application feature a cycling timetable. Our approach extends the work of Van Aken et al (2017).

The proposed model is part of a prototype developed by the Dutch rail infrastructure manager ProRail and the Dutch passenger rail operator Netherlands Railways. Our aim is to support the planning process by finding good solutions for all practically relevant problem instances. In this talk we discuss the methodological and practical challenges we faced, and the lessons we learned, during the development process.

■ TC-42

Tuesday, 12:30-14:00 - Virtual Room 42

Decomposition Algorithms for MINLPs

Stream: Mixed-Integer Nonlinear Optimization
Invited session
Chair: *Stefano Coniglio*

1 - Regularization in decomposition methods for global optimization of Mixed-integer Nonlinear Programming
David Bernal, Zedong Peng, Ignacio Grossmann

Recently, Kronvist, Bernal, and Grossmann proposed using regularization ideas for MINLP[1]. Inspired by the regularization method for continuous convex problems, the authors proposed a method that by solving an additional regularization Mixed-integer quadratic program (MIQP) in each iteration leads to a reduction in the total OA iterations and total algorithmic runtime. In this work, we propose using MILP regularization subproblems to achieve the iteration number reduction and avoid the solution of expensive MIQP subproblems. Both the global version of OA and the regularization approaches, with MIQP and MILP subproblems, have been implemented as part of the open-source Mixed-integer nonlinear decomposition toolkit in Python (MindtPy). This toolkit automatically performs the decomposition and solves the subproblems via Pyomo. MindtPy provides the end-user a seamless way of combining decomposition algorithms, allowing for an easy and transparent way of addressing challenging MINLP instances. Here we present the details of this implementation, together with the theoretical and algorithmic advances required by the methods above, and a benchmark of our tool comparing it with other solution methods for MINLP. [1] Kronqvist, J., Bernal, D. E., & Grossmann, I. E. (2020). Using regularization and second order information in outer approximation for convex MINLP. Mathematical Programming, 180(1), 285-310.

2 - Linearization and Parallelization Schemes for Convex Mixed-Integer Nonlinear Optimization
Prashant Palkar, Meenarli Sharma, Ashutosh Mahajan

We develop and test linearization and parallelization schemes for convex mixed-integer nonlinear programming (MINLP). Several linearization approaches are proposed for the LP/NLP based branch-and-bound algorithm. Some of these approaches strengthen the linear approximation to nonlinear constraints at the root node and some at the other nodes in the branch-and-bound tree. Two of the techniques are specifically applicable to commonly found univariate nonlinear functions and are more effective than other general approaches. These techniques have been implemented in the open-source Minotaur toolkit.

Tests on benchmark MINLPLib instances show up to 12 percent improvement in the average time to solve the instances. Shared-memory parallel versions of NLP based branch-and-bound and LP/NLP based branch-and-bound algorithms have also been developed in the toolkit. These implementations solve different nodes of the branch-and-bound tree concurrently. About 44 percent improvement in the speed and an increase in the number of instances solved are observed when the two schemes are used together on a computer with 16 cores. These parallelization methods are compared to algorithms that exploit parallelism in existing MILP solvers. The latter approaches are seen to perform better thus highlighting the importance of MILP techniques within MINLP algorithms.

3 - Outer-approximations and submodular/Benders inequalities for the maximization of submodular functions combined with a set-union operator
Stefano Coniglio, Fabio Furini, Ivana Ljubic

We study a discrete optimization problem asking for the maximization of the expected value of a submodular, concave, and differentiable function f combined with a set-union operator. The former models the decision maker's utility function, while the latter models a covering relationship between two ground sets, a set of items and a set of metaitems. The goal of the problem is to find an optimal subset of metaitems such that the total utility of the items they cover, as determined by f, is maximized. We propose a double-hypograph decomposition method which allows for projecting out the variables associated with the items by separately exploiting the structural properties of the function f and of the set-union operator. With this technique, the function f is linearized using an outer-approximation technique, whereas the set-union soperator is linearized in two ways: (i) via a reformulation based on submodular cuts, and (ii) via a Benders decomposition. We compare the strength of the resulting inequalities from a theoretical perspective, as well as experimentally within a branch-and-cut algorithm.

■ TC-43

Tuesday, 12:30-14:00 - Virtual Room 43

Urban and Sustainable Transport

Stream: Environmental Sustainability in Supply Chains
Invited session
Chair: *Christian Fikar*

1 - Anticipative fleet planning model supporting the role of rail as a backbone of the future PI transport network
Martin Hrusovsky, Vera Hemmelmayr

The expected transformation of the freight transportation system towards the Physical Internet (PI) and an already rising market volatility cause an increasing shift from rail to road. On one hand, this happens due to the changing demand characteristics, increasing urgency of deliveries, smaller batch sizes as well as a higher economic competition on the road. On the other hand, the decreasing share of rail on the modal split is often also caused by the lack of flexibility and complex planning processes that are often not supported by the appropriate optimization tools.

In order to respond to these challenges, we present a mixed-integer linear program for anticipative fleet planning of railcars, including specific characteristics such as preferences of the customers, flexible and fixed assignment of railcar types to orders, specific lead times for different transport relations as well as specific capacities for each railcar type and type of goods. The objective of the model is to find the optimal assignment of the available railcars to the incoming orders based on the preferences of the customers and the total costs. Moreover, the model is also able to identify potential overstocks and understocks within the current railcar fleet. In this way, the time needed for planning can be substantially decreased and the flexibility can be increased so that the railway companies can react faster to potential changes in demand, as we will show in a short case study.

2 - Evaluating Concepts for Collaborative Passenger and Freight Transport on a Fixed Infrastructure
Lena Hörsting, Catherine Cleophas

As the number of deliveries continues to increase, last-mile transport threatens the quality of urban life by causing high congestion rates and environmental pollution. One conceivable step toward more sustainable transport is to integrate cargo delivery with an existing public passenger transport network. Passenger and cargo vehicles could either share the same rail network or passenger vehicles could be used to also transport cargo by adding wagons or dedicated space. But the planning of such a system is not trivial, as it entails modelling several interlinking planning problems. This work presents a component-based simulation to evaluate different design decisions for collaborative passenger and freight transport in a tram network. A first decision involves the question of whether passenger vehicles transport cargo or dedicated cargo vehicles are needed. Another decision relates to the train schedule and the allocation of cargo. To obtain suitable schedules, we introduce a linear mixed-integer program with a lexicographical objective function. As passenger transport is prioritized, the first objective is to minimize the average number of passengers waiting at stops. The second objective is the minimisation of the mean delivery delay. Finally, we analyse the interplay of these partial decisions in a computational simulation study.

3 - A bi-objective solution procedure to investigating trade-offs between travel costs and quality losses during urban food deliveries
Christian Fikar, Kris Braekers

Within food logistics, the characteristics of perishable items require special attention to deliver products on time and in the right quality to customers. To support related delivery processes, this work presents a bi-objective metaheuristic. It focuses on trade-offs between minimizing travel distances and food quality losses in urban store-based e-grocery deliveries. Varying temperature zones along delivery processes are integrated to calculate quality losses and derive optimal pickup times. Additionally, the procedure includes tailored neighborhood operators, which consider and update current inventory levels at stores in the study area. This enables one to flexible decide where to pick up orders for subsequent shipments to customers. Results of computational experiments highlight the importance of integrating food quality functions in related optimization procedures. Additionally, the specific temperature ranges in stores, on board a vehicle and during loading activities majorly influence related food quality losses.

■ TC-44

Tuesday, 12:30-14:00 - Virtual Room 44

OR in the Cloud

Stream: Practice of OR (Making an Impact)
Invited session
Chair: *Waldemar Kocjan*
Chair: *Susanne Heipcke*

1 - Let your algorithm go out from your PC: How to successfully implement and integrate an OR solution in the Cloud
Michele Quattrone, Waldemar Kocjan, Susanne Heipcke, Jens Schulz, Sofiane Oussedik

After a poll of current cloud usage and experience among the audience, several OR software vendors will give short overview presentations on their offering of cloud-based OR software and services: - FICO Xpress: Leveraging cloud for Enterprise-grade Optimization Applications (presenter: Jens Schulz) - Gurobi (presenter: Michel Jaczynski) -

IBM Ilog: Model, Test, Deploy and Monitor your applications on the cloud (presenter: Alain Chabrier)

In the second half of this session the presenters will be joined by some expert users of OR software for a panel discussion about their experiences, expectations and hesitations regarding the use of OR software on the cloud.

The audience is invited to participate actively in the discussion.

For latest information about speakers and other details, see the 'Making an Impact' web pages Specific sessions - EURO 2021 (https://euro2021athens.com/specific-sessions/)

2 - Leveraging the cloud for Enterprise-grade Optimization Applications
Jens Schulz

"Companies are moving to the cloud. The cloud is the future." I will introduce the main underlying asks by large companies for flexible resource usage, high-availability and scalability of optimization applications and optimization execution services. At FICO, we provide easy means to move analytic development and creation of complete decision management solutions to the cloud. This ranges from open standards and published APIs over easy access to cloud functionality in the modelling language and powerful applications and optimization execution services. Furthermore, because optimization is not just used standalone, integration with rule engines, data science tools, and application development software are key to successfully deployment such models in large enterprises.

3 - Model, Test, Deploy and Monitor your applications on the cloud
Sofiane Oussedik, Alain Chabrier

IBM delivers a broad portfolio of cloud products, including infrastructure, developer tools and services. these include tools to develop and test Machine Learning and Decision Optimization models and deploy them as services. OR in the cloud starts by managing and governing data in the cloud (or on-premise), modeling in the cloud (or on-premise), deploying models in the cloud (or on-premise), then monitoring the workloads and adapting the application components to any changes in the business. IBM Cloud Pak for Data platform allows all these combinations in order to move application to the cloud at each client pace in a managed or self managed cloud.

■ TC-45
Tuesday, 12:30-14:00 - Virtual Room 45

OR in Manufacturing and Digital Twins 2

Stream: Specific Applications of OR (contributed)
Contributed session
Chair: *Pavlos Eirinakis*

1 - The role of Digital Twins and Optimisation in facilitating Digital Transformation in manufacturing
Stavros Lounis, Georgios Doukidis, Yiannis Mourtos

The Industry 4.0 era is already evolving at a fast pace, however not all industries, let alone factories within those industries, have caught up, putting them at a disadvantageous position. In order to rapidly catch up and progress, Digital Transformation (DX) can provide the framework where (a) the Customer experience will be at the forefront, (b) the Business Processes will be redesigned and digitalized, (c) the Business Model will expand and (d) the overall organization will align with a new I4.0 strategy. In this work, we focus on the benefits of introducing Optimization enabled Digital Twins (DT) towards facilitating DX. The goal is to examine the design approach(es) and subsequently the impact of DTs' introduction in the four pillars of DX and their benefits and limitations, as well as the challenges brought forth during implementation in different cases in process industries and discrete manufacturing. In particular our examination includes the DX of a Steel and a Textile manufacturing factory, both utilizing DTs for production scheduling, an Oil Refinery utilizing DTs for on-specs LPG production and an Automotive parts factory utilizing DTs for preventive maintenance during production, all whilst taking under consideration the DTs' enhanced capabilities brought forth by Optimization.

2 - Combined Production Scheduling and Predictive Maintenance for PCB Manufacturing
Yiannis Mourtos, Grigoris Kasapidis, Panagiotis Repoussis, Pavlos Eirinakis

One significant challenge in flexible manufacturing environments is the halt or deterioration of production due to unexpected machine failures. In the era of Industry 4.0, modern production facilities are equipped with a wide range of sensors that capture the performance as well as the health of the equipment. Therefore, production engineers can monitor the condition of the equipment and act early to prevent failures. In this work, we focus on an assembly flow-shop environment with two production stages. The goal is to re-schedule a given production schedule by incorporating preventive maintenance activities for specific machines. Resource constraints are also considered. More specifically, when a job is processed from the first machine of a production stage, the required resources (e.g., semi-finished products, raw materials etc.) for all processing steps should be available. In this work, a constrained programming (CP) approach is proposed for modelling and solving the problem. Computational results using real data from a PCB production line are presented. Results showcase the efficiency of the method as well as the importance of preventive compared to corrective maintenance.

3 - Production scheduling for the steel reinforcement industry
Konstantinos Kaparis, Kyriakos Bitsis, Stavros Lounis

Optimal scheduling is among the most vital aspects of any efficient and effective production line. The so-called Digital Twin (DT) paradigm has been proposed as a tool for real-time optimization of production decision making, including scheduling. Enhancing the DT's with state of the art scheduling algorithms that act in synergy with machine learning and simulation algorithms lies at the core of smart factories. Within this framework we consider the production of a steel reinforcement manufacturer and we develop a Mixed Integer Programming (MIP) formulation for a multistage flexible flow shop scheduling problem with parallel unrelated machines. The model takes into account machine dependent setup times and processing speeds in each stage as well lag times between the processes of two consecutive stages. The objective function is a convex combination of makespan and tardiness. Anomaly detection plays a vital role in the overall scheme and re-optimization strategies are implemented to respond to such requests.

■ TC-46
Tuesday, 12:30-14:00 - Virtual Room 46

Supply chain strategy I

Stream: Production and logistics and revenue management (contributed)
Contributed session
Chair: *Maria Koltsaki*

1 - A Supply Chain Design Model and A Solution Approach Considering Replenishment Frequency and Cross Docking Effects on Inventory and Transportation costs
Aycan Basbozkurt, Kadir Ertogral

In this study, we focus on a three-level supply chain design model which consists of a supplier, multiple depots, and multiple retailers. The problem is to determine the number and the size of depots to open, to decide which retailer to assign to which opened depot, and the replenishment frequencies for each depot and retailer. The model aims to minimize the total system costs including opening and operating costs of the depots, the transportation costs both from the supplier to the depots and from the depots to the retailers and the inventory costs at the depots and the retailers. We assume that the transportation costs between stages have a quantity discount structure, and the depot costs show economies of scale. To achieve a near optimal solution, a periodic inventory control with power-of-two replenishment frequency policy is assumed in order to facilitate the cross docking between inbound and outbound lots in the depots. Distinguishing feature of our model is the integration of strategic decision of opening depots and assigning retailers to depots with the tactical decision of deciding replenishment frequencies, under the power-of-two replenishment policy. As another important aspect of our work, we explicitly model the effects of the cross docking to the inventory and transportation costs. We formulate the problem as a nonlinear mixed integer programming model and suggest a heuristic search based solution approach.

2 - Towards an Optimized Sustainable Blood Supply Chain Network under Uncertainty
Ana Torrado, Ana Paula Barbosa-Póvoa

Blood Supply Chain (BSC) is a challenging subset of the healthcare industry. It treats the blood flow from donor to patient. Considering the scarcity of blood, shortages and wastage are undesirable, as consequence, untreated patients, and even deaths should be avoided. Designing and optimizing BSC processes sustainably is vital. Studies from the last 10 years were analyzed, addressing relevant quantitative models published, according to different planning perspectives and capturing the sustainability dimensions — that rarely are explored together. A brief literature review connected with sustainability is conducted aiming to answer different questions (How to translate sustainability in BSC? How to design, plan, operate a sustainable BSC in an uncertain environment? Where to locate the blood facilities to satisfy demand/supply sustainably?) — that are not completely investigated. We intend to design a sustainable BSC considering the blood group compatibility. The location-allocation problem will be explored considering social (namely, geographical distribution of blood types, geographical and socioeconomic equity that can impact the sum of donation) and costs dimensions. A MILP mathematical model is developed to maximize the social aspects, to minimize the total costs and consequently to maximize the unsatisfied demand. Data available in the National Health System of Portugal is used to illustrate the applicability of the proposed model, and serving as a validation tool.

3 - A fuzzy-based multiobjective optimization of global supply chains
Songsong Liu, Zijing Yang

This work addresses the production, distribution and capacity planning of global supply chains under uncertainty, as an extension from our previous work (Liu and Papageorgiou, Omega, 2013, 41, 369-382). Three objective functions, including cost, responsiveness and customer service level are considered simultaneously, for the optimal production and distribution planning of a two-echelon global supply chain network. Meanwhile, the capacities of the plants in the supply chain are expanded under different strategies. In the multiobjective optimization problem, the uncertainties in cost and demand are considered, which are expressed as triangular fuzzy numbers. A fuzzy-based multiobjective mixed-integer linear programming (MILP) approach is proposed with three objectives: total cost, total flow time and total lost sales. An epsilon-constrained method is a adopted to obtain the Pareto-optimal surface. Finally, a numerical example is investigated, and the obtained results demonstrate the applicability of the proposed model and solution approach.

4 - How 3D printing technology can challenge the conventional business models?
Maria Koltsaki, Evgenia Fronimaki, Maria Mavri

As "disruptive" technologies challenge conventional business procedures, the development of 3D printing technology is expected to transform product design and manufacturing. 3D printing technology enables the production of a wider variety of products, most of which are custom-made products, without incurring any additional manufacturing costs. Markets can be served without requiring companies to warehouse goods at large costs. Two words characterize 3D printing technology and give a significant benefit to its stakeholders; "anything" and "anywhere". 3D production technologies have evolved significantly in recent years. Engineers from various industries are attracted to these technologies because of their ability to extensively transform the nature of production processes, with great design freedom. Using 3D printing specifically to create highly complex components can be a cost-effective alternative to conventional production technologies. 3D printing will accelerate product development cycles, shorten product delivery time, modify the profit structures of companies and reshape future professions and jobs. Businesses will have to re-evaluate their business models, as the reinvention of a business model can itself accelerate the adoption of a new technology. The goal of this study is to examine how 3D printing technology influences the existing business models and their components, including the product, the business network and the revenue model.

■ TC-47

Tuesday, 12:30-14:00 - Virtual Room 47

Customer Satisfaction & Loyalty

Stream: OR in Marketing
Invited session
Chair: *Evangelos Grigoroudis*

1 - A Framework for Enabling Spatial Customers Satisfaction Estimation
Anastasia Saridou, Athanasios P. Vavatsikos, Evangelos Grigoroudis

Decision making models are widely used to assist data-driven decision making. The growing capacity of Geographical Information Systems resulted to the emerge of a new rapid developing research area of Spatial Decision Support Systems as tools capable of efficiently handling spatial information and combine it with OR models to assist decision making in the spatial context. Simultaneously the integration of spatially related data for assisting business decisions is referred as "Geo-Marketing" and aims to develop frameworks that assist knowledge-based marketing decisions supported by geo-analysis. Customer satisfaction consists an important and integral part of both private and public sector organizations because their existence and their booming economy depends on it. MUSA is an ordinal regression based approach used for the assessment of a set of collective satisfaction functions, that the global satisfaction criterion becomes as consistent as possible with customers' judgements. MUSA provides information such as global customer satisfaction and estimates effectiveness and demanding diagrams. Local applications of MCDA methods provide more targeted infomation by offering a deeper interpretation of results for a specific spatial unit than having global information. The current research proposes a framework of extending MUSA to spatial context aiming to investigate local satisfaction mappings, providing more information for interpretation and exploitation.

2 - Individual based composite indicator on customer satisfaction and loyalty based on the B-ID-BoD weighting approach
Milica Maricic, Veljko Jeremic

The growing need of individuals to be ranked led to the creation of different ranking methods and approaches, whereas composite indicators (CIs) as metrics stand out as they provide a single number which summarises a multi-dimensional phenomenon, making it easier to understand and communicate. The policymakers are in need of CIs which are personalised, distinctive, and which capture the individuality of each citizen. Therefore, individual based composite indicators are emerging as they provide in-depth insights on the topic of interest. The aim of this paper is to propose such a CI on customer satisfaction and loyalty during COVID-19 pandemic. The additional novelty of the CI will be that its weighting scheme will be determined using a recently proposed Bootstrap I-distance Benefit-of-the-Doubt (B-ID-BoD) model. Namely, the literature observed full model freedom as the drawback of the original Benefit-of-the-Doubt (BoD) model, so the Bootstrap I-distance is used as an unsupervised approach to impose weight constraints. The data used for ranking will be collected using survey among Millennials. It is expected that the novel individual based CIs will provide insights on the behaviour of younger generation regarding their consumer behaviour in the (post) COVID-era.

3 - An Integrated Multicriteria Model for the Analysis of Customer Satisfaction: The Case of Greek 3PL Service Providers

Christos Tzoulias, Michael Madas, Fotis Kitsios

Third Party Logistics (3PL) Service Providers often tend to overemphasize on improving certain aspects of service quality, such as time reliability, while disregarding or downplaying other, more abstract quality attributes, such as empathy and assurance. In our paper, we aim to develop an integrated, customer-centric, multicriteria customer satisfaction evaluation model that will synthesize multiple customer satisfaction dimensions proposed in existing literature and relevant service quality models (i.e., SERVQUAL). The SERVQUAL model, enhanced and properly adapted to the 3PL sector, constitutes an initial basis for eliciting the high-level service quality dimensions. Furthermore, this is further complemented through a comprehensive literature review (i.e., thematic and density analysis) with additional customer satisfaction criteria and indicators. The hierarchical, customer-centric model is then deployed with the use of Multi-criteria Satisfaction Analysis (MUSA) and demonstrated for the case of the Greek 3PL service providers. The integrated use of SERVQUAL and MUSA models enables a more holistic, customer-oriented analysis of customer satisfaction that would be otherwise hard to quantify, while simultaneously considering important quantitative metrics such as cost, time and reliability. The results of the analysis may help 3PL providers to determine and prioritize their improvement and investments efforts towards increasing their competitiveness in the 3PL market.

4 - Developing strategies with the Multicriteria Satisfaction Analysis: A case study from Tripadvisor

Panagiotis Manolitzas, Niki Glaveli, Stergios Palamas, Constantin Zopounidis

The tourism industry plays a vital role in the economy. In Greece, tourism is amongst the major central sectors of the local economy and a key pillar of economic development. Tourism GDP accounted for 6.8% of total Gross Value Added (GVA) in 2017 (OECD, 2020). Online reviews and ratings provided on internet-based travel sites have increasingly transformed travelers' hotel purchase processes, as well as their behavior in information searching and sharing. However, despite the significance of online hotel guest ratings on internet based travelers' sites, there is still a long way to go towards the integration of on-line ratings data analysis into a comprehensive strategy (Baka, 2016; Schuckert et al., 2015). This study demonstrates how Multiple Criteria Satisfaction Analysis (MUSA) can turn online hotel guest satisfaction ratings from TripAdvisor into a valuable source of information for hotel managers and other hotel industry stakeholders.

■ TC-48

Tuesday, 12:30-14:00 - Virtual Room 48

Production planning and Lot-sizing

Stream: Lot Sizing, Lot Scheduling and Production Planning

Invited session

Chair: *Nabil Absi*

1 - Valid Inequalities for the Proportional Lot-Sizing and Scheduling Problem with Sequence-Dependent Setups

Waldemar Kaczmarczyk

Small bucket models allow for one machine setup operation at most during each period. To ensure a high-quality solution in such models, real periods (macroperiods) are usually split into several short fictitious microperiods with non-zero demand only during the last microperiod of each macroperiod. It is beneficial for such a demand pattern to have during each macroperiod one start-up for each product at most. This paper presents new extended formulations of mixed-integer linear programming (MIP) models that use this condition to tighten the PLSP model with sequence-dependent setups. New models use additional macroperiod binary setup variables to add an aggregated decision level in the branch and bound search tree and to set inventory lower bounds only for macroperiods. Comprehensive experiments have shown that standard MIP solvers find good solutions significantly faster for the new models than known models.

2 - Bringing Together What Belongs Together: Combining Optimization- and Rule-Based Workload Control Concepts

Philipp Neuner, Quirin Ilmer, Stefan Haeussler, Hubert Missbauer, Reha Uzsoy

Workload control (WLC) is a production planning and control concept that seeks to regulate the mean and variability of cycle times by controlling the WIP level and output via order release [1]. Within the literature, two approaches have been developed, largely independently, over time: short-term rule-based procedures, and mid-term multi-period optimization-based models. Although both are based on WLC theory only one paper combines them [2]. We present a hierarchical WLC concept consisting of an aggregate optimization model based on clearing functions (CF) for mid-term order release planning, and a detailed rule-based mechanism (LUMS approach) for short-term order release control. The CF model controls the WIP and release quantities on an aggregate level and smooths the load over a longer planning horizon. Given these targets, LUMS determines the order releases in the short term, maintaining the system state determined by the CF model. Simulation experiments in a job shop environment show that our approach drastically reduces overall costs and due-date deviation at the cost of slightly higher WIP compared to a classic LUMS approach. [1] J.W.M. Bertrand, J.C. Wortmann, Production control and information systems for component manufacturing shops, New York, 1981. [2] G. Zaepfel, H. Missbauer, Production planning and control (PPC) systems including load-oriented order release - problems and research perspectives, International Journal of Production Economics 30(1993) 107-122.

3 - Carbon efficient simultaneous bicriteria scheduling and lotsizing under adjustable production speed - An indicator based system comparison

Markus Hilbert, Andreas Dellnitz, Andreas Kleine

In production planning, the comparison of different production systems is receiving growing interest in recent years, particularly in the context of carbon efficient scheduling and lotsizing. If conflicting performance goals like energy costs and carbon emissions are considered when optimizing production processes, one obtains a Pareto front, of course. Here, comparing different production systems means in terms of bicriteria optimization comparing different Pareto fronts in objective space resulting from the planning process. In so doing, there exist indicators for such a comparison. However, these measures are often neither easy to interpret for decision makers nor are they economically interpretable at all. Consequently, to fill in this gap, we propose an indicator for such a comparison. To show the gist of this indicator, first, we describe the underlying planning process mathematically leading to a sustainable bicriteria mixed integer scheduling and lotsizing program. Next, we present our novel approach and, ultimately, we compare it with selected ones proposed in literature using a scenario analysis.

■ TC-49

Tuesday, 12:30-14:00 - Virtual Room 49

Policy-enabling models in the power sector (online)

Stream: Emerging technical and financial aspects of energy problems
Invited session
Chair: *Afzal Siddiqui*

1 - North American Natural Gas Market and Infrastructure Developments Under Different Mechanisms of Renewable Policy Coordination
Charalampos Avraam, John Bistline, Maxwell Brown, Kathleen Vaillancourt, Sauleh Siddiqui

Renewable Portfolio Standards (RPS) accelerate renewables deployment but their impact on fuel-fired plants remains ambiguous. North American natural gas consumption has been growing due to its decreasing cost in North America, policy initiatives, and its relatively low CO2 emissions rate compared to coal. In this paper, we study the implications for the natural gas sector of more stringent RPS under different coordination schemes in an integrated North American natural gas market. The scenarios assume that Renewable Energy Certificates generated in each region are traded 1) among all countries, 2) only within each country, and 3) only within model regions. We implement the three policies in four different energy and electricity models to generate projections of future natural gas consumption. Subsequently, we feed regional or state-level consumption changes of each model in each scenario to the North American Natural Gas Model. We find that lower RPS coordination among regions results in increased U.S. natural gas exports to Canada, increased Canadian natural gas prices, and decreased net U.S. natural gas exports to Mexico in the long term. Moreover, international coordination of RPS in the electricity sector leads to smaller price discrepancies in the U.S. natural gas market when compared to the Reference scenario.

2 - Energy Expenditure Incidence in the Presence of Prosumers: Volumetric vs Fixed Charge
Yihsu Chen

Distributed renewable resources owned by pro-sumers has been viewed as an effective way of fortifying grid resilience and enhancing sustainability. However, prosumers serve their own interests whose objective is unlikely to align with that of society. Their growing presence in the market may negatively affect less affluent consumers who are financially unable to adopt new technologies. We compare the energy expenditure incidence among different income groups when prosumers are subject to a net-metering and a net-billing policy considering both the wholesale and retail markets. We show that policies exclusively based on volumetric consumption for recovering fixed costs are likely to favor the affluent income group. Among the two policies, net-metering is more regressive than net-billing under the volumetric tariff when the prosumers are selling power into the grid. A hybrid policy, which also features an income-dependent fixed charge and an annual (re)connection fee on prosumers, may potentially improve restore energy equity by leveling the energy expenditure incidence. Such policy is also more acceptable by and appealing to the utilities due to its revenue certainty.

3 - Renewable energy policy and market competition under uncertainty
Ryuta Takashima

A lot of energy and environmental policies for reducing greenhouse gas emissions have been implemented in order to limit the global average temperature. The policies focused on promoting renewable energy include feed-in tariff (FIT), feed-in premium (FIP), and renewable portfolio standards. The policies directly affect the market prices by favoring power produced by renewable energy. Thus, the producers' profit might be influenced by the fluctuation in the market prices as well as the policy implementations. In particular, FIP scheme has a dynamic aspect because the cash flows vary with the market prices and premium. In this study, we examine how uncertainty affects a market equilibrium in FIT and FIP by means of a dynamic model. While at the lower level, the optimal productions for both of renewable and non-renewable sectors are derived in a Cournot-Nash framework, the optimal price in FIT and premium in FIP are decided by maximizing social welfare. When the rate of increase in marginal cost of CO2 emissions is relatively low, the social welfare of FIP is larger than that of FIT, whereas when the rate of increase is relatively high, the social welfare of FIP is smaller due to decreases in consumer surplus. In the case of high rate of increase, however, the proportion of renewable energy in FIP is larger than that of FIT.

■ TC-50

Tuesday, 12:30-14:00 - Virtual Room 50

AI4RAILS IV

Stream: The 2nd International Workshop on Artificial Intelligence for RAILwayS (AI4RAILS)
Invited session
Chair: *Rob Goverde*

1 - Towards Risk Assessment of Learned Computer Vision for ATO
Rustam Tagiew, Thomas Buder, Kai Hofmann, Christian Klotz, Roman Tilly

Automatic Train Operation (ATO) from GoA3 on requires Computer Vision (CV). Machine Learning (ML) as the state of art for CV is still missing in binding technical norms for ATO and therefore requires an extra risk assessment policy for a certification. In this contribution, we consider a deterministic CV subsystem within conventional software and rule out end-to-end learning as well as learning during operation. This CV subsystem is not conventionally coded but learned on pre-recorded data solely ahead of the operation. Learned CV (LCV) neither guarantees zero systemic faults, nor can be fully covered in tests. Furthermore, LCV will be restricted to tighter system boundaries than with manual operation (MO) relying on human perception. The certification policy of the complete system incorporating LCV must at least ensure lower risk within system boundaries than of MO. Our project ATO-Sense will deliver quantitative results on the risk of MO and ATO-Risk quantitative results on how much lower the risk of ATO should be. Once a binding threshold for risk of ATO exists, diverse activities for risk assessment can be executed. This contribution includes an overview of such activities as cross-validation, Bayesian ML and statistics, PFMEA, MCDA, DoE, CV-HAZOP, reinforcement learning for testing, explainable AI and some other emerging techniques for deep learning models. THIS CONTRIBUTION REPRESENTS SOLELY AUTHORS' PROFESSIONAL OPINION, NOT THE ONE OF THEIR EMPLOYER.

2 - Multiple-Train Energy Consumption Minimization in Real-Time Railway Traffic Management
Federico Naldini, Paola Pellegrini, Joaquin Rodriguez

Traffic perturbations in railway systems may give rise to conflicts, which cause delays w.r.t. the timetable. Dealing with them requires solving the real-time Rail Traffic Management Problem (rtRTMP). A subproblem of the rtRTMP is the real-time Energy Consumption Minimization Problem (rtECMP). It defines the speed profiles along with the timing of multiple trains in a given network and time horizon. It takes as input the train routing and precedences computed by a rtRTMP solver and its objective is to minimize train energy consumption and total delay. In this paper, we propose an Ant Colony Optimization algorithm for the rtECMP and we test it on the French Pierrefitte-Gonesse control area with dense mixed traffic. The results show that in 30 seconds a remarkable exploration of the search space is performed before convergence.

3 - AI for self-driving trains
Pavel Popov

AI is a new approach to resolving complicated tasks. The approach, which is not reliable now and not providing the required safety. Simultaneously, AI methods give the best results for resolving tasks like computer vision, predicting, planning, and others. One of the AI tasks is developing autonomous trains, where AI is used for computer vision, predictive maintenance, and timetabling. A vast number of situations that arise during operation, and a massive stream of input data for processing, are of great complexity. Moreover, it is impossible to recreate all possible conditions during testing and check a self-driving train's behavior. The usual solution is to use simulators, which can generate all possible scenarios. However, it is necessary to validate the simulator and prove the identity of on-site tests and simulator tests. Additionally, the current standards, like EN50128, do not allow using AI for safety tasks. It is essential to develop new standards or modernize EN50128 to explain how to apply AI for safety tasks. The solution to these problems is what we do every day, and it is important for us to discuss the approaches and methods based on AI for autonomous trains.

4 - Parameter estimation of train trajectory models using reservoir computing
Alex Cunillera, Nikola Besinovic, Niels van Oort, Rob Goverde

Driver Advisory Systems and Automatic Train Operation devices are examples of onboard railway solutions that are essential for improving train operation in issues like capacity, energy-efficiency, punctuality and service reliability. The effectiveness of such solutions often relies on an accurate calibration of the train dynamics, which are usually described through Newton's second law. This equation depends on several parameters which calibration is usually complex. Moreover, factors like wear, wind and weather lead to spatiotemporal parameter variations that have not been fully determined yet in the existing literature.

This work aims to determine the spatiotemporal parameter variability of the train dynamics by means of a REservoir ComputIng based real-time Parameter Estimator (RECIPE). This framework combines a well-established mathematical state observer, the Unscented Kalman Filter, with a machine learning technique called Reservoir Computing. Onboard location and speed measurements are used as input of the Unscented Kalman Filter to obtain an early estimation of the train dynamics parameters, which is further improved via Reservoir Computing. The proposed framework is trained beforehand using historical data, and then performs real-time estimations. The variability of train dynamics parameters and driving style is studied in different temporal scales and in different corridors using real data from trains running in the Dutch railway network.

■ TC-51

Tuesday, 12:30-14:00 - Virtual Room 51

Airport Capacity Management

Stream: OR in Aviation
Invited session
Chair: *Konstantinos G. Zografos*

1 - An integer programming formulation to allocate series of slots on an airport network
Lorenzo Castelli, Andrea Gasparin, Paola Pellegrini, Raffaele Pesenti

Several authors have introduced mathematical formulations for the airport slot allocation process, and the initial allocation in particular. They mostly replicate the current IATA process, performed on an airport-by-airport basis. However, airports are part of a network. The initial slot allocation should therefore be performed simultaneously at all airports, accounting for flight times to link departures and arrivals. [1] proposes an integer programming formulation to allocate a set of single-day slots on a network of airports. Extending that formulation, this paper additionally models the IATA rule stating that series rather than individual slots are to be allocated. A series of slots includes at least 5 slots at the same time and day-of-the-week, distributed regularly in a season. The objective of the allocation is to minimise airline costs due to the non-allocation of series of slots, their temporal displacement, and the deviation from the requested block or turnaround time for slots of coupled series. Preliminary experiments are based on a network of 152 European airports and consider about 300000 slot requests for seven Fridays of the 2017 summer season. Results quantify the increase of airline costs as a function of congestion.

[1] Pellegrini P, Bolić T, Castelli L, Pesenti R, 2017. SOSTA: An effective model for the simultaneous optimisation of airport slot allocation. Transportation Research Part E: Logistics and Transportation Review 99:34-53.

2 - Passenger-centric Slot Allocation at Schedule-coordinated Airports
Nuno Ribeiro
This research develops an original approach to airport slot allocation that aims to balance the interests of airlines, airports, and passengers. The proposed model optimizes slot assignments under the WASG while minimizing displacement and the cost of accommodating passengers. A major challenge, however, is that this model requires as an input the estimated passenger flows, which are unknown at the time of slot allocation (months before the day of operations). Therefore, we use historical data and machine learning models to predict passenger flows and propose a new formulation to optimize slot allocation decisions accordingly.

3 - Achieving allocation stability in airport slot scheduling decisions
Fotios Katsigiannis, Konstantinos G. Zografos
The administrative Airport Slot Allocation (ASA) process comprises multiple interdependent processes. At the outset of the ASA, airlines submit requests for accessing airport landing/take-off slots and coordinators allocate the submitted requests to slots based on a complex set of priorities. Most airport slot allocation studies focus on the initial slot allocation phase of ASA without considering the value/difficulty of implementing each slot request and the acceptability of proposed allocations. This paper proposes a stable airport slot allocation model formulated as a Mixed Integer Program (MIP) that considers a surrogate cost function for each submitted request and provides guarantees on the stability/acceptability of the generated airport slot schedule. The model integrates time-dependent cost functions both for the airlines and the coordinators which consider multiple characteristics and comply with the requirements of the ASA regulatory framework. Our model enhances existing administrative ASA models since it enables pertinent parties to explore the trade-off between the stability and the gains in terms of displacement and spilled passenger demand.

4 - Predictive and Prescriptive Analytics toward Passenger-centric Ground Delay Programs
Alexandre Jacquillat
Ground Delay Programs (GDP) comprise the main interventions to optimize flight operations in congested air traffic networks. The core GDP objective is to minimize flight delays, but this may not result in optimal outcomes for passengers—especially with connecting itineraries. This paper proposes a novel passenger-centric optimization approach to GDP, by balancing flight and passenger delays in large-scale networks. For tractability, we decompose the problem using a rolling procedure, enabling the model's implementation in manageable runtimes. Computational results based on real-world data suggest that our modeling and computational framework can reduce passenger delays significantly at small increases in flight delay costs, through two main mechanisms: (i) delay allocation (delaying vs. prioritizing flights), and (ii) delay introduction (deliberately holding flights to avoid passenger misconnections). In practice, however, passenger itineraries are unknown to air traffic managers; accordingly, we propose statistical learning models to predict passenger itineraries and optimize GDP operations accordingly. Results show that the proposed

passenger-centric approach is highly robust to imperfect knowledge of passenger itineraries, and can provide significant benefits even in the current decentralized environment based on collaborative decision-making.

■ TC-52

Tuesday, 12:30-14:00 - Virtual Room 52

Supporting Sustainable Transitions

Stream: OR in Climate Policy and Planning
Invited session
Chair: *John Psarras*
Chair: *Haris Doukas*

1 - National Energy System Modeling: Exploring the Pathways Towards Energy Transition and Decarbonization
Fernando Antonio Plazas Niño

A thorough review about the application of optimization modeling in national energy systems is presented and a complete list of pathways focused on energy transition and decarbonization are discussed.

The study is divided in three parts: 1) A presentation of the main optimization models and techniques used to analyze national energy systems; 2) An analysis of the different pathways and scenarios proposed to accomplish the objective of energy transition and decarbonization; 3) A discussion about the challenges and opportunities in the field of energy systems modeling.

Previous reviews have not addressed the national energy system modeling as core of study, and this work looks for closing this gap, and at the same time, it was written in an easy and understandable manner in order to be used as tool for junior researchers starting in the field of energy system modeling.

2 - ECO SENSE LABELING: Leadership In Climate Mitigation And Adaptation
George Stravodimos, Maria Tegou, Ioannis Georgizas, Savvas Louizidis

The reduction of energy consumption and carbon footprint is a top European priority, with local communities having an exemplary role towards climate change mitigation and in need of multidisciplinary interventions that lead to targeted decarbonisation. To support this role, intelligent data analysis systems and innovative visualization methods will be vital to provide services and tools to end-users, for the effective implementation of cost-optimal and environmentally friendly actions. ECO SENSE, aiming to address this important need, focuses on the creation of an integrated platform leading to a homonymous labelling of municipalities, which will comprise four main software and equipment interconnection tools related to mitigation, resilience, forecasting and actions prioritisation, that will apply machine learning algorithms for analysis and prediction, and examine the interaction between end users, external factors, and energy systems. Through the multi-criteria decision analysis, a set of best practices will be created, installed and operated, using quantitative prioritisation and qualitative methods along with a cost-benefit study. Fifteen municipal enterprises will implement ECO SENSE, five of which will ultimately acquire the ECO SENSE label. The results of the holistic scheme will be innovative elements of a broader vision for smart energy and carbon footprint management that support scientific research in the field of environmental responsibility and green policies.

3 - A study on the effect of information privacy concerns and perceived usefulness on the acceptance of advanced metering infrastructure
Do-Hyeon Ryu, Kwang-Jae Kim

Advanced metering infrastructure (AMI) is an integrated system of smart meters, communications networks, and data management systems. The major function of AMI is to measure electricity usage automatically and remotely. The collected electricity usage data can be utilized in consumer load profiling, and then inducing consumers to reduce load during peak time. Although deploying AMI has enormous benefits, several obstacles hindering the adoption of AMI exist. First, information privacy concerns (IPC) are one of the serious obstacles. The electricity usage data can disclose detailed information about the behavior and activities of a particular household. This disclosure could make consumers feel surveilled and invasions of privacy. Second, the benefits of adopting AMI is not clear yet from the consumer perspective. Electric power companies have emphasized that consumers who use a large amount of electricity with irregular usage patterns are potential customers to enjoy benefits of AMI. However, the arguments have not been investigated yet from the consumer perspective. This study examines the effect of IPC and perceived usefulness on the acceptance of AMI. The technology acceptance model with structural equation modeling technique is employed. The results of this study are expected to provide insights to how and why IPC and perceived usefulness influence the adoption of AMI, and help electric power companies establish effective strategies for the AMI penetration in households.

4 - Scaling-up public participation in local energy planning through a Multi-Criteria Analysis method
Apostolos Arsenopoulos, Nikos Mastromichalakis, John Psarras

Air pollution, irrational energy consumption etc, cover a wide spectrum of local energy planning issues that need to be addressed towards sustainability. These challenges go hand in hand with several outcomes on the social axis and thus local municipalities are expected to play a key role in the process through strategic policy making. Policy making underlies high complexity due to the controversial implications of the implemented actions upon citizens. Since citizens have little involvement in the selection of these actions, despite being the main beneficiaries, things get worse. This paper aims to introduce a methodology for integrating public participation in local energy planning, by employing a Multi-Criteria Analysis (MCDA) method called TOPSIS. A set of risks is identified, which could affect the implementation of actions. The process of capturing the citizens' and experts' assessments is based on two questionnaires which differ as to the key question that each stakeholder group is asked to answer. Then, the MCDA framework is applied for both of these groups and their results are weighted and summed to extract the final results, i.e. a prioritisation of actions. The evaluations are captured using a 5-tier numeric scale. This research is co-financed by the European Union and national funds through the Operational Program Competitiveness, Entrepreneurship and Innovation, under the call RESEARCH - CREATE - INNOVATE (project name/code: POLIFOLIO/T1EDK-05167).

■ TC-63

Tuesday, 12:30-14:00 - Virtual Room 63

Last minute changes 4

Stream: Last minute changes
Invited session
Chair: *Georgia Ayfantopoulou*
Chair: *Georgia Ayfantopoulou*

1 - On-Demand Bus Routing Problem with Real-time Traffic and Stochastic Shortest Path
Ying Lian, Kenneth Sörensen

The On-Demand Bus Routing Problem (ODBRP) is defined as a dial-a-ride problem (DARP) with bus stop selection, where each passenger can have alternative stops to board and alight, and the routes together with schedules are completely designed according to passengers' demand. Nevertheless, static ODBRP can hardly fit in reality, one of the obstacles is the time-variant and dynamic traffic condition, for example congestion may cause missed time windows and excessive passenger ride times, thus deteriorate service quality.

To deal with this problem, in this paper, we combine ODBRP with real-time traffic information, which results in time-dependent and stochastic travel speeds. After detecting missed time windows, our objective is to minimize the total user ride time, by a variable neighborhood search procedure. Specifically, the bus can be directed to the shortest path calculated by stochastic dynamic programming, or those passengers can be dropped off at alternative stops, or preceded, or reallocated to another bus. Our experimental results show the overall effectiveness of this real-time control under different degree of congestion.

2 - Enhancing day-ahead airline planning with data-driven flight delay predictions

Sebastian Birolini, Stephanie Franklin, Alexandre Jacquillat, Gabrielle Rappaport

Flight delays are the major drivers of disruptions and unexpected costs in airline operations. It is therefore of paramount importance to get visibility into flights' delays as early as possible and as accurately as possible, in order to minimize their overall impact. In this paper, we collaborate with Vueling Airlines to build predictive models of flight delays and enhance day-ahead planning decisions accordingly. We first assemble a large-scale database of flight-level observations, using airline-specific features, system-wide features and environmental features. Using a quantile regression model, we estimate minimum turnaround times for each pair of flights, and reconstruct each flight's primary (as opposed to propagated) delay. We then develop machine learning models to predict primary delays. Our best model, based on extreme gradient boosting, achieves a mean absolute error of 7-8 minutes—a significant improvement as compared to baseline models using simpler machine learning methods or simpler sets of predictors. Finally, we embed our data-driven delay predictions into a tail assignment model to support day-ahead planning. Out-of-sample results demonstrate that leveraging the proposed predictive model can reduce overall delay costs by 3-5%. Ultimately, this paper shows the potential of combining advanced predictive and prescriptive analytics methods to enhance airline planning and operations decisions.

3 - Airline Network Planning: Data-driven Optimization with Demand-supply Interactions

Mattia Cattaneo, Sebastian Birolini, Alexandre Jacquillat, Antonio Antunes

Airlines routinely use analytics tools to support flight scheduling, fleet assignment, revenue management, crew scheduling, and many other operational decisions. However, decision support systems are less prevalent to support strategic planning. This paper fills that gap with an original data-driven optimization model, named Airline Network Planning with Supply and Demand interactions (ANPSD). The ANPSD optimizes network planning (including route planning, flight frequencies and fleet composition), while capturing interdependencies between airline supply and passenger demand. We first estimate a demand model as a function of flight frequencies and network configuration, using a two-stage least-squares procedure fitted to historical data, and then formalize the ANPSD by integrating the empirical demand function into an optimization model. The model is formulated as a non-convex mixed-integer program. To solve it, we develop an exact cutting plane algorithm, named 2αECP, which iteratively generates hyperplanes to develop an outer approximation of the non-linear demand functions. Computational results show that the 2αECP algorithm outperforms state-of-the-art benchmarks and generates tight solution quality guarantees. Case study results based on the network of a major European carrier show that the ANPSD provides much stronger solutions than baselines that ignore—fully or partially—demand-supply interactions.

4 - Development of Decision Support Systems for the Optimization of Mobility Services

Georgia Ayfantopoulou, Ioannis Mallidis, Josep Maria Salanova Grau

The highly polluting urban mobility ecosystem, characterized by increased car transportation, has resulted in the emergence of Innovative mobility services such as ridesharing and bike sharing. Under this new reality, city planners face critical challenges associated to the optimal planning and control of such services while meeting economic and socially optimal requirements. Four step transport modelling has been largely used as a decision-support tool for policy makers, but the complexity of the new mobility services creates the necessity for lighter methodologies able to provide faster solutions with less data requirements. Still, these will not replace conventional modelling approaches, but at a first level analysis, they will provide initial insights and delimitate the analyses to be done at the next levels. Under tis context, the purpose of this paper is to develop close form solutions that can be employed by urban planners as decision support tools. The developed tools will allow for the stochastic optimization of tactical planning and operational control ridesharing, and bike-sharing decisions under total economic and social optimization objectives.

Tuesday, 14:30-16:00

■ TD-02

Tuesday, 14:30-16:00 - Bulding A, Room A5

Stochastic Dominance in Finance

Stream: Risk management in Finance
Invited session
Chair: *Aleš Kresta*

1 - Analysis of Market and Stochastic Dominance Rules in Portfolio Process with Respect of Capital Requirement.
David Neděla

Modern portfolio theory has become one of the most applied portfolio approaches used by investors. However, this theory can be regarded as a pillar from which in recent years has been derived and adapted a large number of similar portfolio models. The possible approach is to combine a general portfolio model with the discipline of the financial area to find a more suitable strategy for the investment making process. This paper aims to analyse the impact of several technical analysis indicators and stochastic dominance approach in the portfolio decision process in various markets during different time horizons capturing different market conditions. The impact is also examined for the needs of market risk capital requirement analysis based on Solvency capital requirement or Basel III capital requirement. Two strategies of implementation technical analysis rules and stochastic dominance rule into the portfolio creation process are considered. Strategy 1 aims at eliminating the whole market systemic risk with the alternative of investing in a risk-free asset. The second strategy focused on the use of assets meeting particular alarm rules. It was evident from the results that using strategy 1 to find systemic risk during the crisis reduced the risk of the portfolio with similar profitability. Oppositely, strategy 2 is more effective in a period with a growing economy. The advantage of strategy 1 in a crisis period is also confirmed according to the market risk capital requirement.

2 - Efficiency analysis of market risk models with MCDM techniques
Tomas Tichy, Aleš Kresta, Frantisek Zapletal

Performance evaluation of financial models for pricing and risk estimation and subsequent selection of models that should be regarded as efficient is one of the most important tasks of financial engineering. The decision-making units in financial institutions consider various criteria, the most important being the correctness of the obtained results. Notwithstanding, some complex decision-making tasks require model evaluation under various circumstances or with different input data. In most cases it happens that a model, which seems to be perfect under given settings, is outperformed by another model, when the conditions change, and that there is no model that dominates under all circumstances. In this paper we extend our previous results on the topic (usage of Data envelopment analysis as a tool for overall evaluation of market risk estimation models) by application of suitable MCDM techniques. Specifically, we evaluate several market risk models combining selected copula functions and marginal distributions over a large set of probability levels to propose optimal combination of inputs.

3 - Efficiency of Credit Risk Management of Selected Commercial Banks in The Czech Republic
Xiaoshan Feng

Credit risk is one of the major risks in commercial banks. Therefore, whether commercial banks conduct effective credit risk management and employ technology changes with the times are essential. The main aim of this paper is to evaluate the performance of credit risk management reflected on global technical efficiency, pure technical efficiency and productivity change. We employ the Data Envelopment Analysis (DEA) on 12 commercial banks in the Czech Republic over the period from 2012 to 2019, then compare the efficiency scores year by year. Selected banks received lower efficiency scores using variable returns to scale in line with expectations. Moreover, strong evidence from the Malmquist Index showed that the Czech banking sector improved its efficiency during the past 8 years due to innovation in credit risk management. Furthermore, logistic regression results provide the major variables that have influence on the likelihood of banks being efficient under CCR and BCC model.

4 - Stochastic dominance with uncertain preferences
Tommaso Lando

The theory of stochastic dominance has been introduced within an economic framework as a model for predicting a decision maker's choice between pairs of uncertain prospects, without having a precise knowledge of her utility function, but just some information about her risk attitude. To improve such a modelization in terms of flexibility, some recent works establish continua of dominance relations, in which a decision maker's preferences are basically described by a risk aversion or a risk attraction parameter (or both). We study a general theory of stochastic dominance which introduces randomness into such models, by assuming that these parameters, representing preferences, are unknown random variables, to be inferred from data through experiments or surveys.

■ TD-03

Tuesday, 14:30-16:00 - Bulding A, Room 3A

Numerical Methods in Continuous Optimization

Stream: Continuous optimization (contributed)
Contributed session
Chair: *Matthew Stuber*
Chair: *Marco Boresta*

1 - Recent Advances in EAGO.jl: Easy Advanced Global Optimization in Julia
Matthew Stuber, Matthew Wilhelm

The development of EAGO began in early 2017 motivated by the need for an accessible, powerful, and extensible deterministic global optimization solver. Its core functionalities and features were designed for broad applicability to conventional nonlinear programming (NLP) problems with solution speed competitive with commercial solvers. However, the key novelty of EAGO lies in its ability to address a much broader class of factorable programming problems involving non-conventional user-defined functions that may not have explicit closed forms, such as those defined by algorithms, and classes of problems beyond NLPs, such as semi-infinite programming. EAGO's ease-of-use comes from its development as a solver for the Julia programming language that seamlessly integrates with the JuMP optimization modeling language through the MathOptInterface abstraction layer.

In this talk, we discuss the capabilities of EAGO as a world-class solver and research platform. We focus on the most recent developments in EAGO that include: major performance improvements; an extended library of convex and concave envelopes of transcendental functions (e.g., erf, erfc) and a library of activation functions common in artificial neural networks; a new modeling framework for semi-infinite programming; transparent error messaging; and problem classification preprocessing that automates solver routines to exploit special problem structures, such as second-order cone problems and mixed-integer problems.

2 - Mixed Finite Differences Scheme for Gradient Approximation
Marco Boresta, Alberto De Santis, Stefano Lucidi, Tommaso Colombo

In this paper we focus on the linear functionals defining an approximate version of the gradient of a function. These functionals are often used when dealing with optimization problems where the computation of the gradient of the objective function is costly or the objective function values are affected by some noise. These functionals have been considered to estimate the gradient of the objective function by the expected value of the function variations in the space of directions. The expected value is then approximated by a sample average over a proper (random) choice of sample directions in the domain of integration. In this way the approximation error is characterized by statistical properties of the sample average estimate, typically its variance. This work instead is aimed at deriving a new approximation scheme, where linear functionals are no longer considered as expected values over the space of directions, but rather as the filtered derivative of the objective function by a gaussian kernel. By using this new approach, a gradient estimation based on a suitable linear combination of central finite differences at different step sizes is proposed, allowing to characterize the error of approximation in a deterministic way. Numerical experiments on a set of test functions are encouraging, showing good performances compared to those of the methods commonly used in the literature, both in the noisy and in the non-noisy setting.

3 - Inexact Newton-type iteration methods for solving the system of general absolute value equations
Dongmei Yu

Two kinds of inexact Newton-based matrix splitting (NMS) methods are proposed for solving the generalized absolute value equations(GAVE). Global linear convergence of the INMS iteration method is investigated in detail. Furthermore, the new scheme involves the well-known Picard iteration method, the exact MN iteration method,the exact NMN method,the NJ method,the NGS method and the Douglas-Rachford splitting method as the special cases.

■ TD-04

Tuesday, 14:30-16:00 - Bulding A, Room 3B

Humanitarian supply chains

Stream: Humanitarian Operations
Invited session
Chair: *Mehdi Hakimifar*

1 - An application of dominance network analysis on spanish food banks
Laura Calzada-Infante, Coque Jorge, Pilar González-Torre

Food banks are non-profit organisations whose purpose is to collect food suitable for human consumption from different sources (donors), store and distribute through different charities to needed families. They play a critical, decisive role in the short term (emergency contexts) facing crises like the present one caused by the COVID. There are 430 food banks in the European Union, of which 54 are Spanish. These entities have a small limited budget that should be managed efficiently. For such purpose, Dominance Network Analysis compares different Spanish food banks' performance modelling them as production units. Dominance Network Analysis creates a directed acyclic network establishing dominance relationships among them based on their performance. This approach complements Data Envelopment Analysis assessing each food bank's relative position with respect to the rest of the network. In this paper, a topological analysis is done to measure at different levels, from node level to network level, giving a picture of food banks' position in the multidimensional space classifying them into inefficient and efficient ones. This provides a clear vision of all the efficient frontier identifying outliers, critical benchmarks for the inefficient food banks and also guidance to identify in which dimension they need to improve their performance.

2 - Orchestrating Coordination among Humanitarian Organizations
Lea Ruesch, Maria Besiou, Murat Tarakci, Niels Van Quaquebeke

Disasters mobilize hundreds of humanitarian organizations. Despite the common aim to assist beneficiaries, coordination among humanitarian organizations remains a challenge. This is why the United Nations has formed clusters to facilitate information and resource exchange among humanitarian organizations. Yet, coordination failures in prior disasters raise questions as to the effectiveness of the cluster approach in coordinating relief efforts. To better understand barriers to coordination, we developed a grounded theory and augmented the theory with an agent-based simulation. Our theory discerns a cluster lead's roles of facilitating coordination but also investing in its own ground operations. We find that specifically serving such a dual role impairs trust and consequent coordination among cluster members. The additional simulation findings generalize the detrimental effect of the cluster lead's dual role versus a pure facilitator role and specifies it against various boundary conditions.

3 - A lexicographic maximin approach to the selective assessment routing problem
Mehdi Hakimifar, Fabien Tricoire, Vera Hemmelmayr

Immediately after the onset of a disaster, the rapid needs assessment process is carried out to investigate the disaster's impact on the affected community groups through field visits. We construct routes for an assessment plan to cover community groups, each carrying a distinct characteristic, in a balanced way. In order to model balanced coverage, we investigate the lexicographic maximin approach. We define the leximin selective assessment problem, which considers the bi-objective optimization of total assessment time and coverage ratio balancing. We solve the problem by a heuristic approach based on the multi-directional local search framework. We evaluate our model based on real-world data from the 2011 Van earthquake in Turkey.

■ TD-05

Tuesday, 14:30-16:00 - Building Δ, Room Δ105

OR in Agriculture

Stream: Specific Applications of OR in Agriculture, Forestry and Fisheries
Invited session
Chair: *Lluís Miquel Plà-Aragonès*

1 - SWOT analysis and group AHP in management of forest bioenergy production and use
Lidija Zadnik Stirn, Špela Pezdevšek Malovrh, Vasja Leban

The importance of renewable energy has increased drastically in the last decades and will continue to rise. Wood from forests represents an essential segment of renewable energy sources in many countries, also in Slovenia. The growing energetic utilization of wood is expected to intensify the competition for wood between different industries, and between wood production and other forest functions and services. In this light, analysis of special approaches to foster energy wood production and use as well as perceptions of relevant stakeholders are needed. To support decision-makers engaged in this topic we developed a multi-criterial model in which SWOT analysis and extended version of group AHP are integrated. SWOT analysis based on participatory approach enables a hierarchical structure of the problem formed by alternatives, SWOT groups, categories and factors. To determine the weights of all elements controlled in the hierarchical scheme a comprehensive research was bestowed to modifications and improvements of group AHP. Firstly, different comparison scales are introduced, studied and compared to the fundamental scale in the view of inconsistency. Aggregation of individual judgements into crisp group judgment and deriving the priority vectors are accomplished by a newly developed WGMDEA method. Most of the data used in the case study were obtained during the EU funded project COOL, as well as from some national projects dealing with multifunctional forest management.

2 - Production Planning for Land-Based Aquaculture
Peter Schütz, Johan Moldeklev Føsund, Erlend Hjelle Strandkleiv, Jørgen Skålnes

In Norway, acquiring production capacity for salmon farming at sea has become very expensive. The aquaculture industry has therefore shown an increased interest in land-based production. In addition to providing additional capacity, land-based production also allows for the production of post-smolt. Post-smolt is salmon of approx. 1 kg that can be transferred to facilities at sea and reduce the duration of the production cycle there by several months. We study the problem of determining the optimal production plan for a land-based salmon farmer. The objective is to maximize the produced biomass over the planning horizon while observing biological and regulatory constraints. We also presents results from applying our model to a case from a proposed land-based facility in Norway.

3 - Water taxation strategies for North America in the natural gas sector
Andrea Arriet, Timothy Matis, Felipe Feijoo

Natural gas is the most used energy source to generate electricity in the United States. Since 2015, natural gas extraction has dramatically increased as a result of fracking advancement. This promising industry's downside is primarily greenhouse gas emissions, water over-exploitation, and water pollution. Water used for fracking contains chemicals that get the gas out of the rock but pollute the nearby aquifers, threaten the freshwater for human consumption, that every day becomes scarcer, especially in areas of the shale plays. This study assesses various water-taxation strategies based on multiple water scarcity indicators, such as water stress index, water table decline index, and others. The North American Natural Gas Model, NANGAM, a long-term partial equilibrium model, was used to analyze the considered regions' possible pathways. The study covers three countries in North America, precisely Canada, Mexico, and the USA, splitting them into 17 regions. This study's main findings are related to the gas production re-distribution among the areas, moving towards the more minor water-stressed areas. Despite those adjustments, highly stressed areas like central-south USA and North Mexico remain high natural gas suppliers. On the consumer side, demand tends to lower in most scenarios, but still not enough to stop threatening freshwater availability in some of the most stressed areas by 2040.

4 - Empirical analysis of a pig supply chain based on a two stage stochastic optimisation model
Lluís Miquel Plà-Aragonès, Esteve Nadal, Victor M. Albornoz

The paper presents a two-stage stochastic model to optimize a vertically integrated pig supply chain. The model maximizes the benefit calculated from the incomes of the animals and the production costs over the time horizon considered. First stage decisions provide a schedule of animal transfers between farms, facilities occupation and trucks involved in transportation. As the original formulation uses integer variables, it is far to find an optimal solution on due time. Further analysis has been done in order to explore the impact on the technical and economic results by relaxing the integrity of the variables, varying the time horizon and studying the model behavior when parameters affecting to the execution's time are modified.

■ TD-06

Tuesday, 14:30-16:00 - Building Δ, Room Δ103

Large scale optimization II

Stream: Big Data and Optimization
Invited session
Chair: *Natasa Krejic*

1 - A Generalized CUR decomposition for matrix pairs
Perfect Gidisu, Michiel Hochstenbach

We study the problem of approximating data matrices in terms of a subset of actual columns and rows; a CUR decomposition. In this work, we present a generalization of a CUR decomposition to a matrix pair (A, B) where matrices A and B represent two data sets. While the rank-k singular value decomposition gives the optimal set of k linear combinations of all the data points, in contrast, we can also try to find the best set of k columns and rows; this is an NP-hard combinatorial optimization problem. Both a CUR decomposition and a generalized CUR factorization may be viewed as an algorithmic approach for approximately solving this combinatorial optimization problem. This approximation preserves properties (e.g., sparsity, nonnegativity, integer-valued, etc.) of the original data sets thereby allowing for easy interpretation of the reduced-dimension data sets. The intuition behind this generalized CUR decomposition is that it may be viewed as a CUR decomposition of A relative to B. The proposed method may be useful in settings where one is interested in recovering a low-rank matrix that is perturbed with non-white noise. It may also be suitable for applications where one is interested in extracting the most discriminative information from a data set of interest relative to another data set.

2 - Optimization methods for graph clustering
Giulia Ferrandi

We review some methods for clustering graphs. A cluster is a group of nodes with the same properties, e.g., many intra-cluster edges and few extra-cluster edges, or vice versa. We focus on the statistical approach of Newman and Leicht (2007), where each node comes from a finite mixture of multinomials, so one cluster corresponds to one component of such mixture. Model parameters are estimated with a type of expectation-maximization (EM) algorithm, whose convergence becomes slower as the number of vertices grows; in addition, the objective function may have a large number of local optima. Therefore, we investigate Hessian-free methods to speed up convergence of EM algorithm by optimizing either the EM steps or the incomplete log-likelihood function. We apply these algorithms to study causalities in a sequence of events coming from a manufacturing process, and modeled as a directed weighted graph.

3 - Line-search Second-Order Stochastic optimization methods for minimizing finite sums
Natasa Krejic, Daniela di Serafino, Nataša Krklec Jerinkić, Marco Viola

We develop a line-search second-order algorithmic framework for minimizing finite sums. The method combines line searches and suitably decaying step lengths. The key element of the procedure is a two-step sampling in each iteration which allow us to mitigate the non martingale error present in the line search procedure. Stationarity of accumulation points is proved in almost sure sense for functions with Lipschitz continuous gradients while the strong convexity implies almost sure convergence. Numerical experiments, including comparisons with state-of-the art first- and second-order stochastic optimization methods, show the efficiency of our approach.

4 - A Modified Levenberg-Maquardt Method for Large Scale Network Adjustment
Greta Malaspina, Natasa Krejic

We present a numerical optimization approach for the solution of large scale Network Adjustment Problems that arise in localization problems such as GPS positioning, surveying and Wireless Sensors Networks localization. In particular we focus on an adjustment problem that comes from the digitalization of Cadastral maps. We consider a modification of Levenberg-Marquardt method that attempts to deal with the large number of variables and observations. At each iteration of the classical method the search direction is computed by solving a linear system of equations, which is an expensive procedure when the number of unknowns in the problem that we consider is large, and represents the major obstacle to the solution of realistic, large scale, problems. We develop a scheme for the decomposition of the linear system, which consist in computing an approximation of the Levenberg-Marquardt direction by solving a number of independent linear systems of smaller size, defined taking into account the underlying structure of the problem. The convergence analysis of the resulting method is studied under standard regularity assumptions of the objective function. Moreover, the algorithm we propose is tested on realistic adjustment problems and compared with classical Levenberg-Marquardt in terms of both accuracy and computational cost.

■ TD-07

Tuesday, 14:30-16:00 - Building Δ, Room Δ102

Network design and facility location problems

Stream: Routing, Logistics, Location and Freight Transportation

Invited session

Chair: *Ebrahim Mohammadi*

1 - Designing a transit network considering a heterogenous fleet

Javier Durán-Micco, Pieter Vansteenwegen

The Transit Network Design and Frequency Setting Problem (TNDFSP) consist of defining the routes followed by the lines conforming a transit network and assigning a service frequency to each of these lines. A common assumption in the TNDFSP is to consider one type of vehicle, although in practice transit networks have vehicles of different sizes and characteristics. We extend the TNDFSP to assume a heterogenous fleet and incorporate the decision of assigning one type of vehicle to each line. A bi-objective memetic algorithm is used to solve the problem, which minimizes the passenger travel time and the CO2 emissions generated by the system. Different strategies are analysed to solve the problem considering the heterogenous fleet. The results show that the algorithm can successfully generate good solutions for the extended problem, and that it does not require additional computing time compared with the algorithm used to solve the problem with only one type of vehicle. The results for a large instance, with 271 nodes, are generated in one hour of computing time. Moreover, it is shown that it is advantageous to include the heterogenous fleet already during the design of the transit network, since the non-dominated solutions find in this case are better than the ones obtained if the bus types are assigned only once the line plans are already defined. Therefore, the extended algorithm allows to generate transit networks that use the available resources more efficiently.

2 - Facility Location Planning in Pharmaceutical Supply Chains: A Multi-Stage Approach

Rebecca Wehrle, Marcus Wiens, Frank Schultmann

Introduction: The COVID-19 pandemic highlights problems in pharmaceutical supply chains (PSCs), often characterized by single-sourcing and long shipping distances. This prompts discussions about relocating production facilities back to European markets to increase availability. Objectives: This paper aims to analyze factors influencing Facility Location Planning (FLP) in PSCs and their complex interdependencies. Thus, identifying relevant levers for possible relocations of production and storage is enabled to analyze the impact of such measures on the availability of pharmaceutical products. Method: A consideration of specificities of FLP in PSC management leads to a multi-periodic, multi-stage model to analyze site selection in PSCs. In the first stage, an area-based FLP is used to group potential locations, while the second stage incorporates the possible solutions into a multi-criteria decision problem. An exemplary model application for the German sales market provides a sensitivity analysis of the model. Findings: The analysis of location factors accounts for the identification of levers for possible location decisions. It is shown that the multi-stage approach identifies solution areas that focus on delivery capability, besides pure cost optimization. Conclusion: The model shows that strategic location assessments should be made regularly to counteract supply uncertainties and bottlenecks. The analysis of location factors helps to identify opportunities for action.

3 - Integrated cross-dock location and operational planning in retail networks

Tobias Potoczki, Andreas Holzapfel, Heinrich Kuhn, Michael Sternbeck

The presentation focuses on the problem of integrating cross-docks (CDs) into a given retail supply network with the aim of minimizing related logistics costs. These comprise transportation costs, costs for setting up and operating CDs, inventory holding and purchasing costs. We present an IP model for optimizing the number and locations of CDs within the supply network as well as the supplier-individual selection of flow type (cross-docking or direct-to-warehouse shipping) and delivery pattern. We propose a hierarchical decomposition approach for solving the problem. In order to demonstrate the model's applicability to real-life instances and to gain further practical insights we conduct a case study using data from a major European retailer. In this representative study we find that up to 6.3% of related logistics costs can be saved by setting up CDs within the supply network. Extensive numerical experiments and scenario analyses provide further managerial insights into the problem characteristics.

4 - A new mathematical model for Multiple Service locations for Autonomous Vehicles

Ebrahim Mohammadi, Rob Zuidwijk, Marie Schmidt

Autonomous transportation is regarded the next revolution in transportation, and it holds the promise of completely altering the landscape of the transportation sector. However, there are many challenges and uncertainties regarding this transformation, which need to be approached pro-actively. Although there is a clear role to play for operations management, there exist only few studies covering the field, so there are many research opportunities to be explored. One of the unexplored areas is the design and planning of supporting services for Autonomous Vehicles(AVs). This paper deals with strategic planning of service locations for AVs. The literature of AV suggests that AVs will probably require new sets of services on the road in order to be operational throughout their journey. Services such as maintenance, specialized refuelling stations, special parking lots, etc. Finding optimal locations for these new services will be essential for the adoption of AVs. Another aspect of this problem is that the service locations are normally controlled by different players (either public or private parties) with different interests and objectives, that may introduce cooperative or competitive aspects to the problem setting. In order to model this problem, a mixed integer program with multiple decision makers is developed. A numerical example is provided and the social optimal solution and the optimal strategies for the different decision makers have been calculated for this example.

■ TD-08

Tuesday, 14:30-16:00 - Building Δ, Room Δ101

OR in Marketing

Stream: OR in Marketing

Invited session

Chair: *Ali Shantia*

1 - Which ethnic groups to contact first? Impacts of decision makers' cultural backgrounds on innovation adoption in B2B settings
Bram Janssens, Matthias Bogaert

This work adds to the stream of research on the influence of national culture on innovation adoption behavior. Rather than studying the national cultures of people residing in different countries, it examines the impact of the ethnic backgrounds of various decision makers residing in the same country. Unlike other studies, it focuses on both the decision to adopt new products and the timing of adoption. The authors analyze actual purchase behavior in a business-to-business setting with regard to incremental product innovations in the United States. Within organizations, decision makers' cultural backgrounds affect both their decisions to adopt and the timing of adoption. Companies thus should account for the ethnicities of firms' decision makers when developing product launch marketing strategies.

2 - Data analysis of co-authorship network for pharmaceutical marketing
Zeynep Hasgül

This paper proposes a method to search key opinion leaders in the pharmaceutical industry with a network-based approach. The marketing mix of the pharmaceutical industry includes defining key opinion leaders. These leaders are acknowledged doctors in a certain specialty that influences their coworkers. In the classical setting, these leaders are selected with word-of-mouth information gathered by sales representatives. However, face-to-face visits among doctors and sales representatives are becoming unsuitable in pandemic conditions. Furthermore, it is not always cost-effective. The pharmaceutical industry is adapting to digitalization slower as it is subjected to strict rules and regulations. Nonetheless, COVID-19 has accelerated the digital communications strategy. We know that in the scientific community networks can be extracted using articles and coauthors' data. This study argues that the co-authorship network can be used to optimize the spread of information in the pharmaceutical industry for marketing purposes.

3 - Strategic Bidding Of Wind Farms In A Competitive Electricity Market
Ali Shantia, Owen Wu, Roman Kapuscinski

We empirically study how the strategic behavior of renewable generators translates to their higher profitability. Using the day-ahead and real-time market data, provided by Midcontinent Independent System Operator (MISO), we study what differentiates the bidding behavior of wind farms and analyze whether such strategic behaviors practically increase wind generation profitability and how this effect is moderated by market competition and wind intermittency.

■ TD-21

Tuesday, 14:30-16:00 - Virtual Room 21

General papers

Stream: Soft OR and Problem Structuring Methods
Invited session
Chair: *Chris Smith*

1 - Improving problem formulation in ill-defined situations with a decision support system
Christian Hannes, Rüdiger von Nitzsch

Formulating a decision statement is the foundation for systematically solving a decision. In ill-defined decision situations, formulating is particularly difficult. Nevertheless, there is no decision support system (DSS) that helps decision-makers to formulate a high quality decision statement. Developing such a DSS, criteria for high quality decision statements are needed. Within literature, we found the criteria of preciseness and broadness of the decision statement. We developed the DSS ENTSCHEIDUNGSNAVI on basis of the criteria to support decision-makers formulating a high quality decision statement within ill-defined decision situation. Furthermore, it provides a structured and value-focused process to aid decision making. All in all, the ENTSCHEIDUNGSNAVI is the only DSS that helps decision makers converting ill-defined decision situations in well-defined ones to eventually make better decisions. We used the ENTSCHEIDUNGSNAVI in an empirical study with 778 students, dealing with ill-defined decisions. In 464 cases the decision statement was adapted. The ENTSCHEIDUNGSNAVI helped to broaden the decision statement in 73 % of these cases and to specify the decision statement in 69 % of these cases. Nevertheless, we found that broadness should not be used in this generality. It was possible to formulate high quality decision statements even without broadening them.

2 - Problem structuring proposal in a medical clinic of a medium-sized hospital using soft system methodology (ssm)
Samuel Martins Drei, Eliezer Miranda, Tainá da Silva Rocha Paz, Victor Rosemberg Reis Mota, Nissia Carvalho Rosa Bergiante

The Problem Structuring Methods (PSM) allow to represent the situation so that those involved can converge on commitments and at least partially unfold them. With its development, it was possible to spread its different approaches in several contexts, including the healthcare field. In Brazil, the healthcare system proves to be very conducive to structuring problems, especially due to its public bias, in view of its high demands and its resources limited by several factors. Therefore, the present study aims to propose a method for structuring a decision problem in the medical clinic service of a medium-sized hospital in the interior of a Brazilian state, using the Soft System Methodology (SSM). Therefore, the methodology unfolded in the typical steps of the SSM, developing and outlining, first, the flow of processes involving the employees of the medical clinic. From that, it was possible to propose a conceptual model to ease the overload of activities among the ward employees, which was identified as the focus of the problematic. As a result, the model developed in line with real medical clinic data proposes a better balance between the activities of all wing employees, electing primary and auxiliary nurses for each set of activities, taking into account those that they include, or not, displacement between other points in the hospital, distributing the workload more evenly.

3 - Return to presential classes during the COVID-19 outbreak: a wicked problem discussed using VFT approach
Luciano Azevedo de Souza, Marianna Cruz Campos Pontarolo, Guilherme Regal de Castro, Danny Aronson, Nissia Carvalho Rosa Bergiante

With the increase in COVID-19 transmission, Brazil had to impose social distancing measures such as suspending face-to-face classes at universities and replacing them with online ones to preserve the population's health and prevent the collapse of the health system. This created a "wicked" problem in a Federal University of the Brazilian Semiarid. On one side, the region is strongly stimulated by the University's presence, With economy focused on trade and services, in a municipality with less than 12 thousand inhabitants.Thus, this analysis aimed to support the institution's decision-making process through Value-Focused Thinking (VFT). A rich picture was also created and six stakeholders were interviewed, representing the students, the municipality/community, and the University. The use of the rich picture and the VFT made it possible to understand the different stakeholders' values and thereby elaborate the fundamental objectives of the problem, breaking them down into education, health, and the community's economy. Through the network of fundamental objectives, it was found out that health concern is common to all stakeholders. Also highlighted was the concern with access to information and communication technologies, awareness of biosafety measures and real estate vacancy in the municipality. Finally, this study can contribute to other teaching institutions in small cities that are also struggling with the pandemic's difficulties.

4 - Action Research using SSM: Client Interactions, Project Formatting and Rich Picturing
Chris Smith, Giles Hindle, Karthik Suresh

This paper presents action research using Soft Systems Methodology (SSM). It explores the initial stages of SSM projects and how online rich picturing can facilitate the practical viability of the methodology. In particular, we discuss initial client interactions, the role of rich picturing, modelling tactics and project formatting. Our thesis is that a more action-oriented approach to rich picturing is more in tune with client expectations and can increase the likelihood of further work. We make reference to the research programmes of Strategic Options Development and Analysis (SODA) and The Strategic Choice Approach (SCA).

■ TD-22

Tuesday, 14:30-16:00 - Virtual Room 22

Bilevel optimization in investment, planning and production

Stream: Bilevel Optimization
Invited session
Chair: *Francisco Benita*
Chair: *Stefano Nasini*

1 - Nash Bargaining Partitioning for Decentralized Portfolio Optimization
Stefano Nasini

In the context of decentralized portfolio optimization, understanding how to distribute a fixed budget among m decentralized intermediaries is a relevant question for financial investors. We consider the possibility of using the Nash bargaining partitioning for a class of decentralized investment problems, where risk minimizer intermediaries are in charge of the portfolio construction in heterogeneous local markets. We propose a reformulation that is valid within a class of risk measures (that we call quasi-homogeneous risk functions) and allows the reduction of a complex bilevel optimization model to a convex separable knapsack problem. As numerically shown using stock returns data from U.S. listed enterprises, this modelling reduction allows solving large-scale investment instances in less than a minute.

2 - Endogenous Technology Sharing in Decentralized Production
Marijn Verschelde, Stefano Nasini, Bruno Merlevede

The joint nature of knowledge-based assets drives firms to pursue multi-plant production (Markusen, 1995). By facilitating knowledge sharing across plants, integrated firms have higher returns on investment for intangibles in comparison to single-plant firms. We study the endogenous choice of intangible assets by the parent firm, organizing decentralized multi-plant production. A distinguishing feature of our framework is that we allow for anticipation by the parent of the affiliates' best response to the technology transfer and transfer price, set by the parent. Our approach is general in the sense that we cover both horizontal and vertical production and allow for dynamic optimization by the follower. We implement the leader-follower structure by the use of a bi-level optimization framework wherein the parent acts as a newsvendor. For horizontally organized firm structures, we recover the optimal solution and for vertically organized firm structures we recover tight lower and upper bounds. We show the empirical applicability by the use of a customized version of the Orbis dataset that focuses on European firms with complete parent-affiliate balance sheet information at the firm-year level. Our advocated approach nicely recovers stylized facts and pinpoints profit gains that originate from anticipating the best response of the follower.

3 - A GRASP metaheuristic and a GRASP-TABU Search for solving a bi-level competitive facility closing problem.
Juan-Carlos García-Vélez, José-Fernando Camacho-Vallejo, Juan Díaz, Diego Ruiz-Hernandez

In this paper, we consider a situation in which there are two companies offering a service required by a set of customers. Both companies compete with each other and must close some of their existing facilities. When the decision on which facilities are going to be closed is made, the company must take into account the possible actions of the rival one and the reaction of the customers. The objective for each company is to achieve the maximum capture of customers demand in the market. This problem is addressed by a binary bi-level programming model, called (r|p)-Negative centroid. The upper level corresponds to the company with the highest purchasing power, which closes its own facilities. Then, at the lower level the facilities of the other company are closed. This problem consists in deciding the p and r facilities to be closed by both companies, respectively. To solve this problem we propose two metaheuristics: a GRASP and a hybrid GRASP-TABU. The GRASP consists of two phases, one where leader solutions are explored and for each of them the follower problem is optimally solved by using CPLEX; and the other phase consists of performing a local search. In order to intensify the local search we propose a Tabu Search, where the local search phase is exchanged for a tabu search. By using both metaheuristics we can find good-quality solutions to the problem. However, when solving the tested instance by the hybrid metaheuristic, a lower computational cost is reported.

4 - A bi-objective bi-level humanitarian logistics problem
Edith Salinas De LeÓn, José-Fernando Camacho-Vallejo, Carlos Henggeler Antunes, Maria João Alves

After the occurrence of a catastrophic situation, humanitarian logistics aims to help the affected people in the most convenient manner. Usually, it is very diffilcult to anticipate the occurrence of a natural disaster. For this reason, the study of problems that may arise after the impact of a natural disaster is of utmost importance. In this presentation, a bi-level bi-objective programming model applied to humanitarian logistics is discussed. At the upper level, a federal organization makes the decision to open temporary aid distribution centers, in such a way that two main objectives are simultaneously considered: the minimization of opening and allocating costs and the minization of time required to supply aid. Additionally, the state government decides how to distribute the aid to all the demand zones that require such aid, aiming to maximize the minimum aid supplied to a demand zone. Exploiting the structure of the bi-objective bi-level problem, optimality conditions for the lower level are obtained. Therefore, it is reformulated into a bi-objective single-level problem. The reformulation is transformed into a weighted sum and epsilon-constraint methods are designed to obtain a set of efficient solutions. Limited size instances are tested at this stage of the research due to the complexity of the resulting reformulation. We discuss the limitations of the presented approaches and present some ideas of a metaheuristic algorithm.

■ TD-23

Tuesday, 14:30-16:00 - Virtual Room 23

Derivative-free Optimization and Connections to Machine Learning

Stream: Derivative-free Optimization
Invited session
Chair: *Clément Royer*
Chair: *Albert Berahas*

1 - An Accelerated DFO Algorithm for Finite-sum Convex Functions
Aurelien Lucchi

Derivative-free optimization (DFO) has recently gained a lot of momentum in machine learning, spawning interest in the community to design faster methods for problems where gradients are not accessible. While some attention has been given to the concept of acceleration in the DFO literature, existing stochastic algorithms for objective functions with a finite-sum structure have not been shown theoretically to achieve an accelerated rate of convergence. Algorithms that use acceleration in such a setting are prone to instabilities, making it difficult to reach convergence. In this work, we exploit the finite-sum structure of the objective in order to design a variance-reduced DFO algorithm that provably yields acceleration. We prove rates of convergence for both smooth convex and strongly-convex finite-sum objective functions. Finally, we validate our theoretical results empirically on several tasks and datasets.

2 - An Empirical Study of Derivative-Free-Optimization Algorithms for Targeted Black-Box Attacks in Deep Neural Networks
Giuseppe Ughi

We review derivative-free-optimization (DFO) algorithms for the generation of targeted black-box adversarial attacks on Deep Neural Network (DNN) classifiers. We assume the perturbation energy is bounded by an l-infinity constraint and that the number of queries to the network is limited. We introduce a new algorithm built on the model-based DFO method BOBYQA and we compare it to pre-existing algorithms based on genetic, direct and randomized direct-search, in addition to Frank-Wolfe. The experiments show that finding an adversarial example depends on both the nature of the algorithm used and the setting of the attack; algorithms limiting the search of adversarial example to the vertices of the l-infinity constraint work particularly well without structural defenses, while the presented BOBYQA based algorithm works better for especially small perturbation energies.

3 - Analysis of Line Search and Trust Region Methods with Noise
Albert Berahas, Katya Scheinberg

In this talk, we present and analyze general nonlinear optimization methods in the presence of noise. Specifically, we analyze a generic line search method and a generic trust region method in the presence of bounded noise in the objective function and an absence of any derivative information. Our theoretical results match those of the deterministic methods, in terms of the dependence on the desired convergence accuracy. Finally, we present some numerical results showing the practical performance of the methods.

4 - A Study of Direct-search Methods Based on Probabilistic Properties
Clément Royer

In this talk, we review a family of direct-search optimization methods derived from classical schemes by introducing randomness. We describe a generic methodology that leads to complexity guarantees for these algorithms in their deterministic form, which we then adapt to a probabilistic setting: this allows us to identify algorithmic variants that can provably improve the complexity of these methods. We will then illustrate the numerical performance of the proposed techniques on modern benchmarking tasks.

■ TD-24

Tuesday, 14:30-16:00 - Virtual Room 24

Vector and Set Optimization III

Stream: Vector and Set Optimization
Invited session
Chair: *Miguel Sama*
Chair: *Enrico Miglierina*

1 - Some Remarks on Proper Minimality in Set Optimization
Enrico Miglierina, Lidia Huerga, Elena Molho, Vicente Novo

The aim of this paper is to extend the notion of proper minimality from vector optimization to set optimization. In particular, we focus our attention on two notions of proper minimality well known in vector optimization, namely the so called Henig and Geoffrion proper minimality. We introduce a generalization of the first one in the setting of normed vector spaces whereas, for its intrinsic features, the generalization of the second one is considered in a finite dimensional setting ordered by a special class of polyhedral cones. After a comparison of the two notions, we study sufficient and necessary conditions for proper minimality in a set optimization problem by using a linear scalarization tecnique.

2 - Extension of continuous quasiconvex functions
Carlo Alberto De Bernardi

Let X be a nontrivial real normed linear space and Y a subspace of X. The natural problem of extending continuous convex real-valued functions from Y to the whole X was studied by several authors in the last two decades, and positive results were obtained under suitable hypotheses involving separability conditions. After a brief review of known results about this problem, we will present some recent results, obtained in collaboration with L. Vesely, concerning the corresponding problem for the class of continuous quasiconvex functions.

3 - On multivalued variational inequalities
Ruben Lopez, Miguel Sama

We study the existence of solutions and stability results for multivalued variational inequalities for nonmonotone set-valued maps. To do this, we use the horizon map and graphical convergence. We also review the pseudomonotone case.

4 - Numerical Estimates for State Constrained Multiobjective Elliptic Control Problems
Miguel Sama

In this talk we deal with state-contrained multiobjective elliptic control problem, in particular we deal with conical regularization methods (J. Math.Anal.Appl. 479(2) (2019) 2056-2075). We give estimates for the regularization error and we show how we can apply these results in order to get numerical error estimates for a discretization of the original problem.

■ TD-25

Tuesday, 14:30-16:00 - Virtual Room 25

Optimization under Uncertainty for Production and Supply Chain Management

Stream: Stochastic and Robust Optimization
Invited session
Chair: *Francesca Maggioni*
Chair: *Thomas Martin*

1 - Comparison of different approaches to multi-stage lot sizing with uncertain demand
Viktor Bindewald, Fabian Dunke, Stefan Nickel

In this talk we discuss a new variant of the classical lot sizing problem with uncertain demand. We assume that neither the length of the planning horizon nor the demands are known exactly. This setting is very common in practice, where information about the future is only accessible for a rather narrow time window and are revealed gradually over time. Additionally, problem parameters are often based on forecasts or derived from historical data and hence are inherently uncertain. This results in a rolling horizon procedure, i.e., the multi-stage problem dissolves into a series of coupled snapshot problems that contain uncertain parameters. Depending on the available information and the decision maker's risk disposition, different approaches from online optimization, stochastic programming and robust optimization have to be selected to model and solve the snapshot problems. To evaluate the impact of the selected methodology on the overall solution quality we use a recently proposed, methodology-agnostic framework for multi-stage decision making under uncertainty. The talk is concluded by presenting results from a computational study on lot sizing with uncertain demand regarding different types of uncertainty representations, solution approaches and the value of available information about the future.

2 - Dynamic programming for the management of an oil production network problem
Cyrille Vessaire

An oil production network is composed of a reservoir (geological formation containing oil), wells and pipes coupling those wells. Usual formulation of the management of an oil production network problem use decline curves to describe the behavior of the production of each well. Such model imply that each well of the production network are independent (at the reservoir level). We propose a new formulation of the management of an oil production network problem, where the reservoir is a controlled dynamic system. We then use dynamic programming to find the best production planning.

3 - A stochastic dynamic approach to the crude oil procurement problem
Thomas Martin

Crude oil procurement is subject to variations in shipping delays and random costs. The optimal procurement problem aims at buying oil for refineries so as to maximize net revenue. The plants owned by a company have different specifications, and so have the crude oil available on the market. In our setting of the problem, we focus on the stochasticity of the costs of oil, shipping and of the prices of the products. The dynamic of the system over time, the shipping delays, and the running of a refinery are supposed to be deterministic. We will first present a model that features three unique traits. First, a delay exists between the moment an order is placed and the moment it impacts the stocks. Second, decisions, and uncertainties, belong to two different time scales, while purchases are made weekly, consumption of resources is made monthly. Last, target constraints exist on the combinations of crudes that can be purchased. This model results in a multistage stochastic optimization problem which, due to its huge size, is impossible to solve as such.

We then present resolution methods that leverage the peculiar structure of the problem to build robust policies. More precisely, we will detail the use of a varying state size through buffers, of time-blocks decomposition and of constraint propagation. The obtained policies are then tested and compared to standard methods in the industry.

4 - A decomposition algorithm for multi-item tactical planning with independent random parameters
Masoumeh Kazemi Zanjani, Shayan Tavakoli Kafiabad, Mustapha Nourelfath

Integrated planning of manufacturing operations and workforce training is a challenging task in multi-product settings where the demand and/or production lead-time of different items are independent random variables. With a particular focus on maintenance facilities, this study proposes a multi-stage stochastic programming (MSP) model for integrated operations and workforce planning under independent random repair time of faulty components. The goal is to determine the optimal scheduling of repair operations and training sessions for the operators such that the expected number of delayed maintenance jobs due to the shortage of spare parts and certified operators in minimized. Given the assumption of independent random repair times of defective components, the size of underlying scenario tree in the MSP model grows exponentially. Therefore, an approximate decomposition algorithm, based on Lagrangian relaxation approach, is also developed to efficiently solve this model in real-size problem instances. This algorithm relies on decomposing the MSP model into sub-models corresponding to component scenario trees and coordinating them via a sub-gradient algorithm to obtain a high-quality feasible solution. Our numerical experiments conducted on a range of problem instances demonstrate the significant value of incorporating repair time uncertainty in this problem setting and the effectiveness of the proposed solution methodology in overcoming the computational complexity.

■ TD-26

Tuesday, 14:30-16:00 - Virtual Room 26

Interior point algorithms in convex optimization II

Stream: Nonlinear Optimization
Invited session
Chair: *Marianna Eisenberg-Nagy*
Chair: *Petra Renáta Rigó*

1 - An interior-point method for low-rank semidefinite programming with application to truss topology optimization
Michal Kocvara, Soodeh Habibi, Michael Stingl

General purpose algorithms and software for semidefinite optimization are unsuitable to solve problems of very large dimension, often appearing in applications. In order to be able to solve such problems, one has to use their data structure, if available. In this talk, we focus on SDP problems with low-rank solutions. Within a standard framework of an interior-point algorithm, we propose to solve the (Schur complement) linear systems by a preconditioned conjugate gradient method. We present a new preconditioner, tailored to the low-rank structure of the solution. To demonstrate the efficiency of the new method, we solve large to very large scale SDP problems from structural optimization with either a rank-one solution or with an "approximate" low-rank solution. In both cases, our Matlab software clearly outperforms available general purpose SDP software.

2 - A Feasible-Inexact Quantum Interior Point Method for Semidefinite Optimization
Brandon Augustino, Giacomo Nannicini, Tamás Terlaky, Luis Zuluaga

We present a provably convergent quantum interior point method for semidefinite optimization problems, building on recent advances in quantum linear system solvers. The quantization of classical interior point methods is the subject of several recent papers in the literature. However, current QIPMs in the literature are not valid for solving semidefinite optimization problems. We point out several challenges that have been overlooked so far, and propose solutions to these challenges. We compare the theoretical performance of classical and quantum interior point methods with respect to various input parameters, concluding that based on the current state of the art, our algorithm is the first convergent QIPM that provides a speedup in terms of the size of the problem.

3 - Predictor-Corrector Infeasible IPM for Horizontal Linear Complementarity Problems over Cartesian Product of Symmetric Cones
Soodabeh Asadi Dezaki

The horizontal linear complementarity problem over the Cartesian product of symmetric cones (SCHLCP) has been recently dealt with interior-point algorithms after its central path has been proved to exists and to be unique. SCHLCP is a general problem that includes many other problems defined on the symmetric cones with their well-known associated problems on the non-negative orthant such as linear programming problem, linear complementarity problem, and the convex quadratic problem. Here we present an infeasible interior-point predictor-corrector algorithm, based on a large neighborhood of the central path, for horizontal linear complementarity problem over the Cartesian product of symmetric cones. Throughout the paper, we assume that the $P_*(kappa)$ property holds for the SCHLCP problem.

This condition is equivalent to the property of sufficiency for the particular case of horizontal linear complementarity problem (HLCP). The polynomial convergence is shown for the commutative class of search directions.

4 - A new stopping criterion for PCG applied in IPM
Filippo Zanetti, Jacek Gondzio

Interior Point Methods (IPMs) often employ an iterative scheme such as Conjugate Gradient Method to compute Newton directions. The Preconditioned Conjugate Gradient (PCG) is usually applied as a black box solver and the attention is turned to a design of a suitable preconditioner which would accelerate the convergence. We believe that there is much to be gained by adapting the PCG to the problem being solved: in particular, we design and analyze a new specialized termination criterion for PCG applied in the context of IPMs. This novel intelligent Interior Point Conjugate Gradient (IPCG) exploits the structure of the problem and of the specific IPM used, and estimates within the CG algorithm the convergence indicators of the outer IPM iterations. It is therefore possible to terminate early the linear solver, without having to wait for the standard residual convergence test. The new criterion has been tested on a set of linear and quadratic optimization problems including compressed sensing, image processing and some of the Netlib LPs; it has demonstrated consistent and significant improvements both in terms of CG iterations and computational time.

■ TD-28

Tuesday, 14:30-16:00 - Virtual Room 28

The Role of Mathematical Optimization in Data Science IV

Stream: Mathematical Optimization and Data Science
Invited session
Chair: *Alba Olivares-Nadal*

1 - Predicting next purchase behavior from shopping basket data using a supervised LDA approach
Luis Aburto, Andrés Musalem

In retailing, there are many opportunities to use the vast transactional and loyalty card information to improve predictions and support managerial decision-making. This work introduces a supervised Latent Dirichlet Allocation (LDA) model to classify shopping baskets and use them to predict the next purchase amount and the time of the next visit. The prediction of these two metrics is relevant for the design of incentives aimed at influencing customer behavior in the next shopping trip. The model is calibrated using loyalty card data. We rely on Latent Dirichlet Allocation (LDA) as proposed by Blei (2003), which has been widely used in text mining to extract topics from documents, measuring the probability of co-occurrence of words. In our retail context, we will extract latent shopping motivations instead of latent text topics, analyzing relationships among product categories, instead of words, in a transaction instead of a document database. The contribution of this research is then to apply a supervised LDA approach in a retailing setting, modifying the basic model to jointly estimate the latent shopping motivations and the relationship between these motivations and next purchase information such as the amount spend and time lag. We show that we outperform different supervised machine-learning methods to predict the next purchase using previous transaction information in an out-of-sample prediction test.

2 - A Two-step Anomaly Based Method for PU Classification in Imbalanced Data Sets
Carlos Ortega Vazquez, Jochen De Weerdt, Seppe vanden Broucke

Several machine learning applications such as medical diagnosis and fraud detection suffer from incomplete label information. In such applications, a classifier can only train from positive and unlabeled examples, in which the unlabeled data consist of both positive and negative examples. This setting is called learning from positive and unlabeled data or PU learning. Despite the numerous works in the literature, there has been insufficient attention to PU learning under class imbalance: For instance in fraud detection, it is common that fraud occurs in less than 1% of the cases. Thus, we propose a two-step method that exploits anomaly detection to identify hidden positives within the unlabeled data. Our empirical analysis shows that our method generally outperforms other well-known PU baselines under class imbalance.

3 - Mathematical optimization for scoring modelling
Guillermo Navas-Palencia

Scoring modelling is widely used to develop decision systems for critical applications, e.g., in medicine and finance. Scoring models are globally interpretable regression or classification models, amenable for models under GDPR, that must satisfy multiple operational and behavioural (e.g., fairness) constraints.

Scoring modelling uses binning techniques to discretize a numerical variable into bins given a discrete or continuous numeric target. We consider several rigorous and extensible mixed-integer programming formulations to solving the optimal binning problem for a binary, continuous and multi-class target type, incorporating constraints not previously addressed.

The classical binning algorithms return a discontinuous piecewise constant function, assigning the same transformation to all values within a given interval. This approach enables simple explanations but has several implications such as a reduction in granularity and being a source of unfairness due to discontinuities. To tackle these issues, we introduce a continuous piecewise polynomial fitting formulation, representing a good compromise between accuracy and explainability. This method requires several adjustments to the general scorecard format while ensuring its simplicity.

We present examples and performance results of both methods using the implementation in the open-source library OptBinning.

4 - Feature Multiproduct Newsvendor with Substitution
Alba Olivares-Nadal

In this paper we aim to improve the decisions taken in a centralized multi-product newsvendor problem by making use of information provided by exogenous features. We rely on dual theory and the well-known kernel trick in order to account for nonlinearities and interactions between features without increasing drastically the dimensionality of the problem. In the case of a single item, the problem reduces to a Support Vector Quantile Regression. When decisions should be taken for more than one item, we allow for substitutions between products in case of scarcity and we show that the problem can be equivalently formulated as a quadratic program. When fixing or penalizing the direction of the substitution demand flow, we allow for a possibly high-dimensional augmentation of the feature space. The results show that incorporating information from features and accounting for nonlinearities and interactions tractably provides statistically significantly better performance than the benchmark approaches.

■ TD-29

Tuesday, 14:30-16:00 - Virtual Room 29

AI - Big Data for Decison Making

Stream: AI and Decision Making
Invited session
Chair: *Fatima Dargam*

1 - Batch retrieval order optimization for vertical lift modules
Pieter Vanhauwermeiren

Vertical lift modules use trays to store products in vertical storage racks and deliver these products to a picking opening where a picker can pick the ordered products. The efficiency of a VLM system is determined by the total completion time, the time to pick all ordered products, and can be increased in multiple ways: using multiple VLM's together, grouping the orders into a batch, or using more advanced VLM configurations. Even when several of these methods are implemented, the operator still has to wait for the next tray to be retrieved or has to walk to the next VLM which decreases the overall efficiency. In this paper, an optimization model for retrieving a complete batch from a VLM is presented with the objective to reduce the total completion time by minimizing the waiting and walking time. The model is created for the 5 frequently used VLM configurations and multiple storing strategies. In a first model only 1 VLM is considered to eliminate the walking time, but when the capacity is not enough multiple VLM's can be considered. Results from numerical experiments show that the total order time can be reduced by optimizing the batch order and that this model can easily be implemented in already existing batching systems.

2 - Application of Machine Learning for Economic Valuation of Data: A Data Engineering Approach
Shivani Shukla, Mouwafac Sidaoui, Bill Schmarzo

The relatively inexpensive computing power, fast and targeted solution development and the advent of cloud-based solutions have enabled data-driven decision making at every level of an organization and facilitated coordinated efforts that superpose traditionally soiloed approaches. In a world of data democratization and availability of large storage capacity and computation products, valuation of data becomes key to strategic prioritization. In this paper, we use a data engineering approach combined with the prudent value approach to measure the financial value of data based on the extent it is used or leveraged in an organization. We propose a novel methodology that is implementable by organizations depending on the business initiative at hand.

3 - Multicriteria Spatial Decision Support System for natural gas distribution networks expansion
Naylil Liria Baldin de Lacerda, Carolina Lino Martins, João Batista Sarmento dos Santos, Edson Antonio Batista

The natural gas segment has been undergoing transformations due to the increased demand and availability of new technologies. To seek competitiveness, natural gas companies need to optimize network energy distribution planning by consolidating an interactive and dynamic project portfolio. In order to improve the decision-making process for companies in this sector, this research proposes a Multicriteria Decision Aid model integrated with a Spatial Decision Support System (SDSS) to define a portfolio for the expansion of natural gas distribution networks. The study uses a benefit-to-cost ratio (BCR) approach to select portfolios under incomplete information about criteria scaling constants with the FITradeoff method. The SDSS is a computerized interactive system based on the geographical data of the projects. The Multicriteria Spatial Decision Support System (MC-SDSS) MC-SDSS aims to provide flexible and analytical tools for spatial analysis and support to select the best project portfolio.

■ TD-30

Tuesday, 14:30-16:00 - Virtual Room 30

MILP algorithms for routing problems II

Stream: Mixed Integer Linear Programming
Invited session
Chair: *Maria Battarra*
Chair: *Gunes Erdogan*
Chair: *Reza Shahin*

1 - Stochastic Approaches for Truck/Drone Tandems in Humanitarian Applications
Hannan Tureci Isik, Melih Çelik, Ece Sanci

Humanitarian relief operations provide humanitarian aid in natural or human-made disaster situations such as transporting emergency packages or rescue teams to the disaster area. Humanitarian operations rely mainly on logistics. Ground vehicles, such as trucks, traditionally constitute the main means of transportation. On the other hand, potential damages on the road infrastructure in the aftermath of a disaster may deem some or all demand locations disconnected from the road network. In such a case, the use of drones to overcome network inaccessibility has significant potential. The extant literature in logistics considers trucks and drones together in parcel delivery and report shorter route durations than the truck-only delivery systems. A limited number of studies on humanitarian applications exist but fail to recognize the disaster-related uncertainties in the problem environment, such as demand amounts or condition of the road infrastructure. The aim of this research is to develop mathematical modeling and solution approaches to address the problem of locating depot locations prior to a disaster and subsequent post-disaster relief transportation by trucks and drones simultaneously, considering the uncertain aspects of the problem environment. These models and approaches will be implemented using datasets that mimic realistic post-disaster scenarios.

2 - A trajectory optimisation-based heuristic for routing unmanned aerial vehicles in a disaster assessment application
Walton Pereira Coutinho, Joerg Fliege, Maria Battarra, Anand Subramanian

We consider the problem where a fleet of unmanned aerial gliders is required to photograph a number of points of interest, such as hospitals, schools and residential areas, in the aftermath of a disaster. Each glider is subject to flight dynamics constraints and must stop at one of the available landing sites. We aim at balancing the duration of the gliders' routes by minimising the maximum route flight time. To efficiently solve this problem, we propose a hybrid algorithm consisting of: (i) a sequential trajectory optimisation heuristic (STO), designed to cope with the very challenging task of finding feasible (flyable) trajectories for a given route; and (ii) a routing matheuristic which combines iterated local search and a set-partitioning-based integer programming formulation. In turn, our STO framewok is based on two main trajectory optimisation sub-problems: a non-linear formulation that accounts for the flight time on each arc of the routes and associated discretisation errors; and an iterative heuristic that minimises the discretisation errors for a fixed flight duration. Preliminary tests showed that the proposed algorithm was capable of quickly finding feasible solutions for randomly generated instances with up to 50 waypoints.

3 - A branch-and-cut algorithm for the vehicle routing problem with three-dimensional loading constraints
Felix Tamke, Leopold Kuttner, Florian Linß

We present a new branch-and-cut algorithm for the vehicle routing problem with three-dimensional loading constraints. We introduce several cuts to eliminate routes with infeasible loading based on different constraints considered in the loading problem, such as LIFO unloading and stability. Violated cuts in integer solutions are exactly separated by a new constraint programming model for the three-dimensional loading problem. To quickly identify routes with feasible loading, we also present an extreme point based packing heuristic, where possible placement points are augmented by normal patterns. This allows to reduce the number of expensive calls to the constraint programming model to speed up the solution process. In addition, routes that are identified as feasible by the separation algorithm are stored and periodically combined in a set partitioning problem during optimization to generate new heuristic solutions. We test our algorithm on well-known benchmark instances and prove for the first time the optimality of some best-known solutions and present new optimal and best solutions for multiple instances.

4 - MILP for a MAST system
Reza Shahin, Pierre Hosteins, Pierre-Olivier Vandanjon, Paola Pellegrini

Mobility Allowance Shuttle Transit (MAST) system is a type of public transportation where vehicles may deviate from a fixed route to serve customers who wish to get on or off within a service area. The service to these customers is operated on-demand: pick-up and drop-off requests are submitted in advance and the vehicle routes are planned to satisfy them as efficiently as possible. Some algorithms exist in the literature to plan these routes. However, they often consider assumptions limiting their practical applicability. For example, typically only one vehicle with infinite capacity is available. In this work, we propose an algorithm to tackle MAST. In particular, we consider a variant of this system modeling a French case study. Here, fixed-route shuttles are allowed to deviate from their route in order to serve customers within predefined geographic areas located at the route extremes. We consider realistic constraints such as those linked to vehicle capacity and fleet availability. The algorithm is based on the solution of a mixed-integer programming formulation. The results suggest that large size instances are solvable but a meta-heuristic approach might be more suitable for better fitting the on-demand nature of the problem.

■ TD-31

Tuesday, 14:30-16:00 - Virtual Room 31

DSS Applications -3

Stream: DSS
Invited session
Chair: *Jason Papathanasiou*

1 - Joint maintenance and quality control for unreliable manufacturing systems

Dorsaf Daldoul, Nadia Bahria

This paper considers a joint maintenance and quality control in manufacturing systems which are subject to a degradation process that directly affects the quality of the produced items. Process and product quality control is carried out using an 'x-bar' control chart. According to the average of the measurements of the quality indicator x compared to control limits, it is decided to undertake or not a maintenance action. The main objective of this paper is to determine simultaneously the economic parameters of the control chart and the optimal maintenance strategy, which minimize the expected overall cost. A combination of mathematical formulation, simulation and optimization techniques is used to solve this problem. The obtained results show clearly strong interactions between maintenance and control chart design which confirm the necessity of jointly considering these functions in an integrated model. Moreover, it is shown a significant impact of production system state on the economic control chart design and therefore on the product quality.

2 - Strategies to deal with epidemics using a system dynamics model: development on real-life experience

Alvimar Lucena, Mischel Carmen N. Belderrain

The epidemiological SIR (Susceptible-Infected-Recovered) model is used to explain contagious disease dynamics and is also an integral part of System Dynamics models tutorials, demonstrating the viability and easiness of that method. Derivatives from the SIR model, including Deceased, Exposed and vaccination effects have been constantly studied once new viral deceases are being periodically identified by an increasingly efficient world viral oversight. From a summary VFT (Value-Focused-Thinking) analysis, the greatest value goal in pandemic response policies and strategies should be established as preservation of lives. So, the author improved a previous system dynamics model on COVID-19. The improved model can support the development of strategies and policies as well as simulate the effectuation of these policies, predicting trends and outcomes, and is based on current experience on pandemics, like the numbers of its spread, non-pharmaceutical measures taken by States, and the behavior of various populations. Model Refinement was supported by statistical studies on regions in the World and by an agent-based simulation of the possible real-world outcomes of different levels of population movement restriction. The calibrated model allowed concluding that the 'stay-at-home' policies, although effective, are not efficient once brings side effects when not executed at ideal levels and that the applied vaccines should have minimum efficiency to allow real epidemic control.

3 - PROMETHEE-SAPEVO-M1 a hybrid approach and decision support system for multicriteria evaluation in complex scenarios

Miguel Moreira, Carlos Francisco Simoes Gomes, Marcos dos Santos

With the involvement of multiple circumstances and scenarios, the complexity of a decision-making analysis is increased from the moment that different points of view and perspectives related to the importance or preference of a variable may influence the decision context. In this context, is presented a new approach based on Multiple Criteria Decision Analysis named PROMETHEE-SAPEVO-M1. The proposed modeling approaches the integration of two multicriteria methods, the PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations) and the SAPEVO-M (Simple Aggregation of Preferences Expressed by Ordinal Vectors - Multi Decision Makers), integrating quantitative and qualitative assessments through cardinal and ordinal inputs respectively, where the ordinal evaluation is also performed as a preference indicator between criteria, in search to obtain its global importance and consecutively their respective weights. The approach provides three models of preference analysis, such as partial, total, and interval preference analysis, in addition to an intra-criterion analysis by veto threshold, allowing the decision-maker to make a sensitivity analysis, comparing the results suggestions under different forms of manipulation through the same data set. In search to support the modeling implementation effectively, was developed a web platform enabling a trivial implementation and robust analysis, through the exploration of numerical results and graphical resources.

■ TD-32

Tuesday, 14:30-16:00 - Virtual Room 32

Trade-off between Economics and Environment: the response of cities in the shadow of COVID-19 1

Stream: Multiple Criteria Decision Analysis
Invited session
Chair: *Alessandra Oppio*

1 - A choice modelling for exploring new housing needs in post-COVID 19 era

Marta Bottero, Marina Bravi, Caterina Caprioli, Federico Dell'Anna, Marta DellOvo, Alessandra Oppio

COVID-19 has imposed severe restrictions and forced confinement in their homes in Italy, as in many countries around the world. Rethinking the way of life and the new inter and post-pandemic needs relating to the use of domestic spaces, necessary for working, studying, or carrying out other daily activities is required by the unpredictability that we still live today. The Politecnico di Milano and the Politecnico di Torino, with the collaboration of Scenari Immobiliari, have launched a survey with the aim of exploring the new residents' needs and preferences in the metropolitan cities of Milan and Turin. The aim of the research is to understand the preferences of residents with respect to the different attributes of housing units and to understand which needs arise during the lock-down period able to influence the willingness to modify the interior layout of their houses. To investigate these preferences, a questionnaire has been administrated using the Best-To-Worst Scaling (BTWS), or Max-Diff methodology, developed by Louviere and Woodworth (1990). The goal is to obtain an ordering of the housing attributes, asking the interviewee to select the best and worst option. The questionnaire was disseminated through various social platforms to obtain a representative sample of the various socio-demographic profiles. The preliminary results provide an overview of the adaptability of currently inhabited spaces through their modification or the need to buy or move houses.

2 - Hybrid Decision-Making Processes for Conflicts Management in City-Port Regeneration

Maria Cerreta, Simona Panaro, Giuliano Poli

According to the Urban Agenda, the concept of urban development recognizes that cities play an essential role in Circular Economy (CE) processes, influencing consumption model, urban resource management, business enablers, and drivers, and governance, supporting the Circular City Model (CCM). The CCM leverages knowledge systems and developmental change methodologies to support the sustainability paradigm shift, as multi-dimensional transformation processes where the governance plays a relevant role. In this framework, port areas have been assumed as a driver for the regeneration of city-port and metropolitan territories, in compliance with the EU Directive 2014/89 which considers maritime spatial planning as a tool for public authorities, promoting the development of maritime and coastal economies and the sustainable use of resources. In order to boost a Circular City-Port Model, identifying the priority actions that could be implemented to activate and consolidate CE processes, integrating and improving existing resources, the selection of sustainable design strategies' portfolio related to two cases studies has been explored. This study structures and tests a hybrid decision-making process combining Multi-Criteria Decision Analysis (MCDA) approaches supporting the elaboration of a spatial transformation and development strategy, and the identification of possible coalitions among the relevant stakeholders.

3 - Facing the demands of green areas in post-COVID 19 cities: a multidimensional evaluation of Ecosystem Services provided by green roofs.

Alessandra Oppio, Caterina Caprioli, Marta DellOvo, Marta Bottero

The current COVID-19 pandemy has shown the intrinsic weaknesses of cities and the reasons why they are not well-equipped to respond to the new emerging needs. However, the social and health crisis we are experiencing can provide an opportunity for thinking about long-term strategies aimed at making cities more resilient, inclusive, green, circular and smart through a new approach to open spaces. In major cities, green spaces are the only chance citizens have to experience nature. Green roofs with the other green spaces form the city's green network that contribute to improve quality of life and wellbeing of citizens. The present contribution aims at evaluating green roofs according to an ecosystem perspective, by considering the evidence of their benefits on inhabitants' wellbeing, their ability to mitigate climate change and to preserve biodiversity. An integrated evaluation model is proposed to take into account the different dimensions of value in the study of Ecosystem Services (ESs) and to support decision makers (DMs) in the definition of actions able to increase the quality of life in cities. The proposed methodology evaluates the biophysical and economic values provided by ESs, by integrating cost-based (initial, maintenance and operating costs) and value-based approaches (socio-cultural values through Multicriteria Decision Analysis). The integrated framework is applied for the analysis of the overall values produced by a green roof project in the city of Turin.

■ TD-33

Tuesday, 14:30-16:00 - Virtual Room 33

Health Analytics

Stream: Business Analytics
Invited session
Chair: *Richard Weber*

1 - Social Networks to detect and mitigate covid outbreak

Constanza Contreras, Carola Sanchez, Mauricio Soto, Richard Weber

Stopping the spread of Sars-Cov-2 infection is one of the principal health challenges nowadays worldwide. Acquiring information on the size and shape of the outbreaks is crucial for improving public policies. In the present work, we construct social networks of COVID-19 cases. We compute social network analysis metrics to assess the quality of traceability strategies and illustrate the propagation of Sars-Cov-2 in the southeast area of Santiago, Chile. Using georeferenced and anonymized data of infected people and their close contacts, we model a virus-spreading network with 20,000+ nodes. We analyze the network's properties and its centrality measures characterizing each outbreak over time. This allows us to establish indicators that provide guidance for decision-makers to improve TTI strategies (tracing, testing, isolation) and reduce contagion. In the current context of insecurities regarding the role of vaccination programs, the difficulties faced by risk communication and the emergence of new variants, non-pharmacological interventions will continue to play a fundamental role. Knowing the dynamics of people's interactions and the spread of epidemic outbreaks through social networks will provide valuable information to face the new scenario that lies ahead.

2 - Predicting patients health status using machine learning

Joaquin Sepulveda, Andres Garrido, Susana Mondschein, Richard Weber

Efficiently monitoring the evolution of patients infected with Sars-Cov 2 is critical due to a large number of infected people and limited capacity of primary care centers. Therefore, home care is essential for non-critical patients, and a thorough and systematic monitoring protocol is mandatory for those cases.

Since resources for personalized follow-up are limited, we developed an Interactive voice response (IVR) system collecting health data for a potentially huge number of patients which are fed into our predictive model. This model allows predicting and determining population risk factors, and thus helping to focus resources towards patients with higher risks, and support medical staff to make data-driven decisions.

In the present work, we use different Machine Learning models that allow us to determine a patient's risk (patient's probability of being hospitalized or dying) in different stages of the evolution of the illness, using symptoms and comorbidities data from phone calls and face-to-face follow-ups in the Southeast Area of Santiago, Chile.

Thus, the goal of this work is to assist the decision-maker to (i) refer patients classified as lower risk to an Interactive voice response (IVR) system, and (ii) assign health personnel to attend and monitor patients with higher risk, in order to make preventive actions and cover a larger number of patients.

3 - Longitudinal Symptoms Analysis of COVID-19 Patients

Alejandro Bull, Angel Jimenez-Molina, Richard Weber

It is known that the SARS-CoV-2 infection manifests itself differently in different groups of patients, either due to the duration of the disease, the presence of certain symptoms, or the order in which they appear. By understanding the symptomatic evolution behavior, patients can be clustered into groups with similar disease manifestations, allowing better clinical decisions about tracing, hospitalization, and treatment. A dataset was extracted from a longitudinal follow-up conducted by the Public Health Service of the southeast area of Santiago, Chile. 231,445 records of 27 symptoms self-reported by 2,719 infected patients (Mean Age = 39.3 years, SD = 19.8 years, 1,566 female) were used. After selecting the most explicative symptoms, K-Modes' unsupervised clustering algorithm was applied to assess symptoms' longitudinal dynamics. Results show three overall symptomatic trajectories within eight different symptomatic clusters (Calinski Harabasz Index of 53 and Davies-Bouldin Index of 4.1). The first trajectory was characterized by anosmia and dysgeusia over ten days. The second trajectory started with headache and myalgia, symptoms that on the third-day change to dry cough over two weeks. Other mild symptomatic clusters were characterized with a few symptoms (odynophagia, myalgias, or headache) over the first 3-5 days. These results confirm findings obtained by recent similar studies in other countries.

■ TD-34

Tuesday, 14:30-16:00 - Virtual Room 34

Discrete-continuous or stochastic control and optimization, and space-time design

Stream: Combinatorial Optimization
Invited session
Chair: *Gerhard-Wilhelm Weber*

1 - Route planning under uncertainty with fuzzy and robust approach
Tereza Sedlářová Nehézová, Michal Škoda, Helena Brozova, Robert Hlavatý

The contribution shows how the combination of fuzzy modelling and robust optimization can be used for route planning in emergency management. In the event of an unexpected disaster, the authorities must act quickly and secure necessary emergency service. In such situations, it is likely that the access to the area by the means of usual paths might not be fully available or even possible. We introduce a robust approach that allows one to plan routes with uncertain travel times and fuzzy modelling approach using fuzzy linguistic scales for setting up the uncertainty set. A methodology of determining worst-case expected scenarios of emergency service is developed, based on the decision-maker's verbal evaluation of critical situation and robustification of the mathematical model of shortest path. The gamma-robustness approach is used, which requires a decision maker to specify and quantify his/her pessimism and also a degree of impact of the disastrous situation. The presented approach is shown on real data based on the earthquake that happened on June 23, 2020, in Oaxaca (Mexico).

2 - The Generalized Ubiquity Generator (UG) Framework – Towards UG version 1.0
Yuji Shinano

The current generation of supercomputers will have over a million cores. The Ubiquity Generator (UG) framework is originally designed to parallelize state-of-the-art branch-and-bound based solvers. Towards UG version 1.0, it is redesigned to the Generalized UG framework. The goal of the Generalized UG framework is to make massive parallelization available to a wide range of optimization solvers and to enable easier use on a broader range of optimization applications on more cores. The UG Framework successfully parallelized Mixed Integer Linear Programming and combinatorial optimization problems, such as the Steiner Tree Problem in Graphs and the Shortest Vector Problem, using more than 100,000 cores. In this talk, we will present the Generalized UG and also introduce success stories for several applications.

3 - Clusters of high-dimensional interval data and related Boolean functions of events in Euclidean space
Jinwook Lee, Andras Prekopa

Clustering interval data has been studied for decades. High-dimensional interval data can be expressed in terms of hyperrectangles in real d-space (or d-orthotopes) in the case of real-valued d-attributes data. This paper investigates such high-dimensional interval data: the Cartesian product of intervals, or a vector of interval. For the efficient computation of related Boolean functions, some interesting aspects have been discovered using vertices and edges of the graph, generated from the given set of events. We also study the lower and upper-bounded orthants in real d-space as events. We show that there exists a polynomial-time algorithm to calculate the probability of the union of such events. This efficient algorithm has been discovered by constructing a suitable partial order relation based on a recursive projection onto lower-dimensional spaces. Illustrative real-life applications are presented.

4 - An Approximate Dynamic Programming Approach for the UAV Dispatching in Airborne Wireless Networks
Cihan Tugrul Cicek, Max Shen

We address the dispatching of unmanned aerial vehicle base stations (UAV-BSs) in a wireless network to reduce the total cost due to handover activities and non-coverage considering the backhaul and battery capacities. The UAV-BSs are assumed to be controlled by a central unit and fly autonomously. Our model jointly determines the trajectories as well as dispatching and charging time of the UAVs, bandwidth allocations, and user assignments for a finite planning horizon. We formulate the problem as a Discrete-Time Markovian Process (DTMP) with continuous state and action spaces and develop an Approximate Dynamic Programming (ADP) algorithm. The computational experiments with synthetically generated data show that our approach significantly reduces the cost and improves the network coverage against a state-of-the-art clustering algorithm. We also test our algorithm on a case study in which the call detailed records including sms, call, and internet activities of tens of thousands of users gathered from the city of Milano. The results confirm that the ADP approach can significantly improve network performance by efficiently routing the UAV-BSs with more flying times and fewer relocation distances.

■ TD-35

Tuesday, 14:30-16:00 - Virtual Room 35

Pension risk management

Stream: Actuarial modeling and risk management
Invited session
Chair: *Susanna Levantesi*

1 - Financial sustainability of an NDC pension system with LTC benefits
Massimiliano Menzietti, Susanna Levantesi, Lorenzo Fratoni

The need for Long term care (LTC) service continues to rise due to the increasing number of elderly in the world, stressing health care systems. As most of the LTC recipients are over 65, several authors studied retirement products combining a lifetime annuity with a long-term care benefit (typical examples are Enhanced Pension and Life Care Annuity). Developing an integrated strategy can help to address the issue related to the cost of care for pensioners affected by disability. Moving from these considerations, this paper proposes a model integrating an LTC benefit into a notional defined contribution (NDC) system. We investigate the financial sustainability of such a system and apply ABM based on Solvency Ratio or Liquidity Ratio. The presence of LTC adds new risk elements, such as the uncertainty related to disability rates and mortality rates of disabled. We address the risks of the system using the Conditional Value-at-Risk (CVaR) of the reserve fund. The main economic and demographic variables involved are modeled in a stochastic environment.

2 - Progressivity in Individual Pension account and life expectancy heterogeneity
Keivan Diakite

Rising empirical studies have showed the positive relationship between lifetime income and life expectancy at retirement. The distortion of income during the active part of the career translates into the amount of retirement benefits one might receive, leading to actuarial unfairness inside cohort of retirees. In order to discuss unfairness and sustainability issues the Belgium pension reform committee issued a proposal for a point system set to be both sustainable and adequate. An individual pension account system has also been proposed as alternative. In this paper we use this pension account framework in order to set a compensation mechanism linked to life expectancy heterogeneity during the active part of the career aiming to reduce unfairness once reaching retirement. This method is based on the progressivity of pension benefit formulae. We implement these ideas in a simple demographic context first in order to capture the constraints related to the models before generalizing them.

3 - On the assessment of the payment limitation for health care expenditure
Fabio Baione, Davide Biancalana, Paolo De Angelis

The study deals with the assessment on the set of optimal reimbursement limits to be applied in a Health Plan that provides the reimbursement of medical procedures and treatments to its policyholders. In a Health Plan the economic balance between the premiums and the reimbursement of medical procedures and treatments is also reached by defining a set of co-payments, co-insurance, deductibles and out-of-pocket limits on each episode. These limits help insurers control risk by making policyholders responsible for part of their healthcare costs, whereas policyholders can cap their share of healthcare costs. To this aim, we firstly consider a standard frequency severity approach to estimate the expected health care expenditure by means of the Generalized Linear Models. Then, a mathematical model is formulated to solve the reimbursement limits problem, i.e., the simultaneous definition of reimbursement limitations, in such a way that the total net asset value over a predefined time-horizon is maximized under constraints on the ratio between health care costs and reimbursements are satisfied.

4 - Fulfilling Consensus: Bitcoin Cross-market Price Convergence
Jinqiang Ye, Jeremy Cheah, Ming-Chien Sung, Zhuang Zhang, Johnnie Johnson

Witnessing an unprecedented price spurt since launching, Bitcoin has attracted rising exposures to various stakeholders. An examination of cross-market inherent consensus formation given existing market wide heterogeneity can be a novel approach towards Bitcoin's unobserved price process and valuation. Our strategy quantifies collective dynamics among international bitcoin markets via cross-market risk-return distances. We link price dynamics among major Bitcoin-fiat pairs as distance-dependent measure regarding risk-adjusted return position. Empirical evidence supports a solid convergence pattern from both individual markets and the aggregated market perspectives, and we thus draw inference on cross-market consensus. We further discuss the impacts of positive and negative macroeconomic shocks on convergence, followed by an analysis of impacts brought by converging trends on information sharing efficiency amongst selected Bitcoin markets. Our distance measures in addition serve as a model-free instrument to uncover pricing mysteries for emerging and zero-fundamental speculative assets.

■ TD-36

Tuesday, 14:30-16:00 - Virtual Room 36

Dynamical Models in Sustainable Development I

Stream: Dynamical Models in Sustainable Development
Invited session
Chair: *Pierre Kunsch*

1 - Facing climate change: Does Switzerland have enough water?
Juan Esteban Martinez Jaramillo, Ann van Ackere, Erik Larsen

Climate change has created a new challenge for energy systems. On the one hand governments target a reduction in emissions by replacing fossil fuel sources in electricity generation by renewables. On the other hand, renewables generate variability in the generation, producing a mismatch between demand and supply. In this context, Switzerland has voted for a gradual nuclear phase-out, while planning to invest in renewable sources such as PV. To be technically possible, this replacement should be accompanied by an increase in storage facilities (pumped hydro-storage). One question that policy makers should answer is: given the climate change, will it be possible to satisfy an increasing demand with lower water resources? We develop a System Dynamics model to evaluate different climate change scenarios. These scenarios incorporate changes in water inflow and demand pattern, as well as the introduction of a water reserve margin proposed by the Swiss government. Our findings could be used by policy makers as a guide for energy planning.

2 - A dynamic method for the estimation of GHG emissions from land management and planning policies in the Integrated Assessment Model WILIAM
Noelia Ferreras Alonso, Ivan Ramos, Amandine Valerie Pastor, Tiago Capela Lourenço, Margarita Mediavilla, Gonzalo Parrado, Stavroula Papagianni, Leorely Reyes, Luis Javier Miguel

Land plays an important role in global cycles of greenhouse gases (GHG), and therefore in the emissions or removals of GHGs from the atmosphere. As land system is not only key to combat climate change, but it is also essential to sustain life, land use decisions and policies can be only properly evaluated through an integrated approach. This study describes a novel approach to dynamically calculate GHG emissions due to land-use changes over time. Based on System Dynamics (SD) theory, the proposed methodology allows to estimate CO2, CH4 and N2O emissions from land use activities, such as forest management and livestock, and from land use changes. The methodology is based on the IPCC 2006 Guidelines (Volume 4). Information from other models, such as GAINS, GLOBIOM or GCAM is also incorporated to build the approach. Equations vary by land use, and consider the specificities of regional climate, vegetation and soil conditions. Besides, different management practices are included, as the emissions in grassland and cropland vary greatly by their intensity of management. The computational method will be integrated in WILIAM model (Within Limits Integrated Assessment Model), which is being developed in the LOCOMOTION H2020 project. This new feature will link land and climate modules allowing the evaluation of the effects of land-use decisions on the transition to a low-carbon society, thus helping in the design of appropriate land management and land-based mitigation policies.

3 - Hybrid MOPSO-RO model for designing reliable electric public transportation networks
Christina Iliopoulou, Orfeas Karountzos, Athanasios Kopsidas, Konstantinos Kepaptsoglou

Electric buses have emerged as a promising alternative to diesel vehicles under the paradigm of sustainable public transportation services. However, planning for electric bus systems comes with its own set of challenges and unique considerations related to energy provision. Indeed, electric public transport systems are vulnerable with respect to energy supply and transmission, as power level fluctuations and grid failures can prevent buses from adequately charging at designated points, affecting extended areas of operation. So far, the reliance on the electric grid has been unaccounted for in existing studies handling the design of electric public transport networks. In this context, this study addresses research gaps by presenting a bi-level modeling framework for designing robust electric public transport networks, taking into account power supply uncertainty. To that end, an Integer Programming model is embedded into a multi-objective Particle Swarm Optimization (MO-PSO) framework, in order to simultaneously design transit routes and deploy charging infrastructure under energy supply uncertainty. The widely adopted robust optimization (RO) uncertainty set-based approach is employed to obtain solutions under power supply variability. The model is applied to a well-known benchmark instance from the literature. Results demonstrate that design objectives are interlinked with robustness, as the effects of uncertainty consideration vary depending on the design objective.

4 - An analysis of the electricity transition in Belgium without nuclear energy
Pierre Kunsch

This presentation analyses the adequacy of the current policy of the Belgian government for complying with the European Union objectives for decarbonising the production source of electricity on the Belgian grid. It is shown that none of those objectives will be achieved should the governement maintain the outphasing law of nuclear electricity pushed forward by green parties.

■ TD-37

Tuesday, 14:30-16:00 - Virtual Room 37

Digital Ethics & Governance

Stream: Ethics in OR
Invited session
Chair: *Ulrike Reisach*
Chair: *Cindy-Ricarda Roberts*

1 - Fracturing Common Sense: Profiling, Targeted content and Self-isolation
Javier Lede

During the COVID19 outbreak, physical distancing became a key public health strategy to cope with the spread of the virus. The growing ecological imbalance may result in new hostile environments, in which the practice of self-isolation become recurrent. Such scenarios make relevant to understand a juncture where reclusion measures collide with current information and communications technologies. This paper explores the impact of digital platforms, whose business model is centered on profiling and targeted advertising techniques, in relation to self-isolation. To this end, a qualitative research was conducted under grounded theory methodology, based on a theoretical sampling of 25 in-depth interviews with 21 participants from the Metropolitan Area of Buenos Aires, Argentina, whose experienced long isolation policies as public health measures in the face of the pandemic. The research findings support the thesis that isolation accelerates a process in which algorithmic filters are fostering a dimension of social divide in which multiple mutually inconsistent narratives are build. The incongruence occurs on the basis of "alternative facts" that underpin new webs of meaning. This erodes "common sense", because it creates parallel semantic networks with irreconcilable categories of "truth", fracturing the rhetorical foundations on which democratic consensus can be built.

2 - Digital teaching and learning - opportunities & threats and their ethical aspects
Ulrike Reisach

Digital learning has become a major practice during the Covid-19 lockdown, in most countries of this world. In order to classify different types of opportunities and challenges and evaluating their ethical aspects, this study uses a Strength/Weaknesses/Opportunities/Threats (SWOT) analysis to compare different approaches and where/how they are being used: (S) Technologies, teaching and learning innovations; (W) Issues with connectivity, regulations, privacy, digital literacy, grading modes; (O) Goals, disciplines, course sizes, teaching-/learning styles, competencies to be acquired, and (T) Challenges for motivation, holistic understanding, interaction and collaboration, fairness, physical and psychological well-being. Based on the analysis, issues such as digital and societal divide, fairness, protection and regulation, consequences for learning results, freedom of science, and the role of universities will be discussed.

3 - Mobile Artificial Intelligence Applications for Skin Cancer Diagnostics: Preferences and Concerns of Digital Natives
Sarah Haggenmüller

Artificial Intelligence (AI) has shown potential to improve early skin cancer detection. However, translation of AI-based diagnostic tools into clinical practice can only be successful if they are accepted by potential users. Young adults as digital natives may offer the greatest potential for successful implementation into clinical routine, while at the same time representing the future generation of skin cancer screening. We conducted an anonymous online survey (n=728) to examine how and to what extent individuals below 35 years of age are willing to accept AI-based mobile applications for skin cancer diagnostics. Descriptive analysis and statistical tests were performed to evaluate participants' attitudes towards mobile applications for skin examination. An adaptive choice-based conjoint was integrated to assess respondents' preferences using hierarchical Bayes estimation. Potential concerns were evaluated using maximum difference scaling. Altogether, the majority of potential future users below 35 years of age was ready to accept AI-based diagnostic solutions for early skin cancer detection. However, for translation into clinical practice, participants' demand for increased transparency and explainability of AI-based tools seems to be critical.

4 - Augmented Intelligence for Transparent Decision Making in Insurance Claims
Swati Sachan, Jian-Bo Yang, Dong-Ling Xu, Karim Derrick, Xi Liu, Chris Stubbs, Harvey Maddocks, Miranda Chong

An insurance claim decision requires claim handlers to understand the circumstances that give rise to the claim, knowledge of procedural rules and regulations, and critical reading and in-depth analysis of evidence from multiple information sources. Insurance claim processing is demanding for the handler and can be intimidating for the defendant and claimant. Many insurance companies have started to leverage the potential of AI to automate repetitive tasks and augment the cognitive capability to provide efficient and trustworthy decisions for improved customer experience.

This paper presents a methodology to capture and transform the claim handlers knowledge into the degree of belief for a set of decision-making rules. It is a transparent hybrid probabilistic expert system; a decision can be explained by the importance of the rules, weight of attributes, and the belief-degree in a decision inferred from the rules that are activated by the information of a given claim. The transparency of the decision-making system engenders trust in computer-aided decision making. Historical data may not contain rare claim circumstances. Therefore, a human expert can be leveraged to make decisions for such claims, which are then added to the training data for future machine learning from humans. This framework allows human experts and an AI system to work in partnership to enhance each other's capabilities.

■ TD-38

Tuesday, 14:30-16:00 - Virtual Room 38

Dynamical Systems and Mathematical Modelling in OR 2

Stream: Dynamical Systems and Mathematical Modeling in OR
Invited session
Chair: *Margarida Catalão-Lopes*

1 - An Attacker–Defender Sequential Game
Krzysztof Szajowski

There are an attacker trying to collect some data in the information system and the defender (the guardian) whose aim is to keep data in the system safe, protecting by preventing unauthorized downloading of data, identification of the adversary through the pre-emptive action. Both sides will be able to observe the system. At every stage n they can see the state of the system which can be modeled as realization of the random process. Their possible decisions are the moments of interventions. The aim of the attacker and defender is presented by a pay-off function which reflects the general principle that deactivation of the attacker should be complete. It leads to the two player non-zero stopping game. In the paper the closed form of the game solution is presented. The model is closely related to a sequence of independent Bernoulli trials studied by Hill and Krengel (1992), proper Sakaguchi's (1984) game and the priority stopping game of the author & Ravindran (1992).

References Hill, T., Krengel, U (1992): On the game of googol. Int. J. Game Theory 21(2), 151-160.

Sakaguchi, M. (1984): Bilateral sequential games related to the no-information secretary problem. Math. Jap. 29, 961-973.

Ravindran, G., Szajowski, K. (1992): Non-zero sum game with priority as Dynkin's game. Math. Jap. 37(3), 401-413.

2 - Strategic Interactions of Urban Land Developers in the Housing Market

Margarida Catalão-Lopes, Pedro Garcês, Cesaltina Pires, Joana Pinho, Sílvia Jorge, Adriana Alventosa

Demand in the housing market has been widely studied in the literature but the housing supply side is still understudied. The monocentric city models explain observed patterns of land prices and population densities. Main results show that housing price decreases with distance to the central business district (CBD) and the farther away an agent lives from the CBD, the more housing units he consumes (larger houses). These models have been extended in multiple ways but remain to be a building block for the analysis of location within a city. The vast majority of the literature on housing markets assumes that the housing industry is perfectly competitive, with a few exceptions. However, the existence of differences in the housing quality, differences in housing accessibility, differences in households' tastes, can be sources of market power and lead to strategic interactions between the urban land developers (ULD). This article introduces duopoly competition with vertical product differentiation. We discuss a dynamic duopoly game with two stages. In the first stage, the two ULD simultaneously choose the quality of housing and then simultaneously choose prices. We assume that one of the urban land developers is located at the CBD while the other is located at a more peripheral area. This article provides a full characterization of the Nash equilibrium of the second stage price competition game, considering all possible market coverage configurations.

■ TD-39

Tuesday, 14:30-16:00 - Virtual Room 39

Synchronized multi-stakeholder freight transportation systems

Stream: Routing, Logistics, Location and Freight Transportation

Invited session

Chair: *Teodor Gabriel Crainic*
Chair: *Ioana Bilegan*
Chair: *Tayeb Oulad Kouider*

1 - A Deterministic Approach to the Synchronized Location-Transshipment Problem with Multi-Commodity Flows

Riccardo Giusti, Teodor Gabriel Crainic, Daniele Manerba, Roberto Tadei

The Synchronized Location-Transshipment Problem with multi-commodity flows is the problem faced by a logistics service provider that must locate transshipment facilities to manage many customers' origin-destination shipments while minimizing the total location-flow cost. We study this problem in the context of synchromodal logistics that requires the use of different transportation modes (e.g., truck, rail, navigation) to perform long-haul transportation and the synchronization of the operations. In this work, we propose a MILP formulation in which origin-destination demands of containers with different release and due dates are considered. To address synchronization, we build a multi-periodic network with penalties for early and late arrivals, i.e., storage costs and customer compensations for late deliveries. Balancing those penalties with operational costs activates consolidation mechanisms. The model is addressed with a commercial solver to perform economic analyses. The facility bundle constraints forbid splitting the problem into single-commodity flow ones, making it hard to solve, the commercial solver requiring high computation times to find a solution. We therefore also propose a solution method based on decomposition, fitting the specific problem features. The performance of our approach, in terms of the objective function and CPU times, is compared with that of the commercial solver.

2 - Global synchromodal shipment matching problem with dynamic and stochastic travel times: A reinforcement learning approach

Wenjing Guo, Teodor Gabriel Crainic

Global synchromodal transportation involves the movement of container shipments between terminals using ships, barges, trains, trucks, or any combination among them, through integrated planning at a network level. One of the challenges faced by global operators is the matching of accepted shipments with multi-type services in an integrated global network with dynamic and stochastic travel times. The travel times of services are unknown and revealed dynamically during the execution of transport plans, but the information on the stochastic travel times is assumed available. Matching decisions can be updated before shipments arrive at their destination terminals. The objective of the problem is to maximize the total profits over a given planning horizon. We propose a sequential decision process model to describe the problem. Due to the curse of dimensionality, we develop a reinforcement learning approach that learns the value of matching a shipment with a service through simulations. Online decisions are made based on the estimated value functions. The performance of the reinforcement learning approach is evaluated in comparison to a myopic approach that does not consider uncertainties and a stochastic approach that sets chance constraints on feasible transshipments under a rolling horizon framework.

3 - Tactical capacity planning in an integrated multi-stakeholder system

Gita Taherkhani, Ioana Bilegan, Teodor Gabriel Crainic, Michel Gendreau, Walter Rei

This study focuses on investigating tactical planning of an integrated multi-stakeholder system. The system receives time-dependent requests from carriers and shippers and optimizes in time and space the operations and transportation activities through consolidation of loads of different shippers into the same vehicles and synchronization of activities. The aim of tactical planning in this system is to build an efficient service network and schedule to satisfy the regular demand and requirements of shippers by making use of the predicted services and their capacities offered by the carriers. The decisions to be made are to select the transportation services offered by carriers, schedule the services that will operate, select the shipper-demand requests to move, identify the demand itineraries, and find the terminals where the shipments need to be stored temporarily with the objective of maximizing the profitability of the system. A novel mathematical formulation of the problem is introduced. Extensive computational analysis is performed on the split and unsplit shipment-flow versions of the problem to evaluate the solution potential of the proposed model with emphasis on the effect of the choice of parameters.

4 - Revenue Management in Inland Waterway Transportation: a planning and execution framework

Tayeb Oulad Kouider, Ioana Bilegan, Igor Crevits, David Duvivier

Freight inland waterway transportation (IWT) is an opportunity for reducing gas emissions and road traffic. Nevertheless, IWT cannot directly satisfy demands outside its network. To cope with this weakness, IWT should be integrated in an effective and competitive intermodal transportation system. Thus, IWT activities need to be accurately planned and synchronized with the other modes, in order to propose attractive and adapted offers of interest for new customers. First, we aim at identifying information requirements to apply revenue management concepts to foster synchromodality. Second, we design an execution management framework to improve operations performance. We propose a decision process where the accept/reject mechanism integrates an estimation of the profitability of each new incoming demand. The profitability is estimated by using a mathematical model explicitly considering forecasted future demands. In case of acceptance, an optimal predictive routing is computed. In case of rejection, an analysis is performed to find out the determining factors. This information is used to describe different scenarios and potentially aid the negotiation with the customer. The execution management framework allows monitoring the transport activities and providing fallback actions for potential incidents to ensure efficient operations. Our work is based on real data and scenarios from the ground.

■ TD-40

Tuesday, 14:30-16:00 - Virtual Room 40

Realistic production scheduling

Stream: Scheduling and Project Management
Invited session
Chair: *Rubén Ruiz*
Chair: *Jérémy Berthier*

1 - Exact and metaheuristic solution methods for a bi-objective industrial scheduling problem with resource dependent processing times.

Oscar Estupinan, David Cortes

This project is a real case scenario, developed in an injection molding company located in Colombia. The company injects millions of pieces per year, using a complex production environment supported by hundreds of molds and injection machines. Currently production programmers can't provide a schedule to fulfil demand and customer service.

The problem was addressed with MILP and heuristic solution methods. Currently aren't any project directly related to ours. The main differences in our project are: minimization of Cmax and tardiness, resource related times (not machine related, innovative constraint), duplicity for some resources with higher performance to the original ones, eligibility constraints related to resources and jobs, setup times between jobs.

Our MILP model works fine for small & medium instances, due to the complexity of the problem, large instances couldn't be solved in planned time, so the authors developed a population-based metaheuristic to reach quality solutions in reasonable time. Our project is focused in solving academic and challenging industrial instances, looking to achieve mutual goals.

2 - Supply chain planning in the chemical industry - systematic literature review and contingency analysis

Philipp Willms, Marcus Brandenburg

For decades, production planning and scheduling in the chemical process industry has been a major field of study for researchers and practitioners. We provide a systematic review of production scheduling problems from the chemical process industry. In total 107 papers are coded against inductively and deductively developed structural dimensions and analytic categories along the dimensions of material flow, production flow and sequence, uncertainties, concerned industrial sectors as well as financial and non-economic factors. The evaluation of the coding results is furtherly enhanced by a contingency analysis. We identify most common characteristics of chemical production scheduling problems as well as their combinations in the form of clusters. Furthermore, we detect recent trends and future research perspectives for the corresponding domain.

3 - Heuristics for fixed and model-dependent task assignments in manual mixed-model assembly lines with walking workers

Seyyed Ehsan Hashemi Petroodi, Simon Thevenin, Sergey Kovalev, Alexandre Dolgui

This talk deals with a multi-manned mixed model assembly line balancing problem with walking workers. We study the impact of model dependent task assignment, workforce reconfiguration, and equipment duplication in mixed-model assembly lines. The model dependent task assignment means that the tasks' assignment to stations may change depending on models entering the line. We propose a new Mixed Integer Linear Programming (MILP) model aiming to minimize the total workforce and equipment costs. To solve larger size instances, we reformulate the problem based on the minimum cost flow problem using dual programming. In addition, we develop a constructive matheuristic and fix-optimize heuristic. The computational experiments performed with reported benchmark instances in the literature ensure that the proposed approaches perform well in terms of solution quality and computational time. The results highlight that model dependent task assignment provides less equipment cost and the number of workers in compare with fixed task assignment. Moreover, the model dependent task assignment performs better than fixed scenario, especially when: 1) the number of models increases 2) the number of model units in the line is restricted 3) models have different precedence graphs 4) models have different sets of tasks.

4 - A multi-objective optimization model for scheduling in the photolithography area in semiconductor manufacturing

Jérémy Berthier, Stéphane Dauzere-Peres, Claude Yugma

Semiconductor manufacturing includes the most complex manufacturing processes. Scheduling problems to be addressed at the operational level involve a rich set of constraints and criteria, especially in complex production areas such as the photolithography area considered in this presentation. This scheduling problem consists in scheduling a set of jobs on a set of parallel photolithographic machines. Each job requires an additional resource, called reticle, that must be transported from one machine to another. Jobs also need to be processed with a given priority, and time elapsed between some of them must not exceed a maximum time lag.

The above scheduling problem is addressed through a time-indexed Integer Linear Programming (ILP) model extending the works of (Bitar et. al, 2021). Based on the factory requirements, several objective functions are considered at the same time in the optimization problem, which makes it multi-objective. Overall, three categories of criteria are studied: — Those implementing relaxed time constraints ; — Those defining production targets of the manufacturing area ; — Those aiming at improving the industrial efficiency. In order to reduce the number of objective functions, the relationship between them is analytically studied: inclusion between the respective optimal set of solutions is investigated for each pair of objective functions. In particular, several results are shown for the classical single-machine scheduling problem.

■ TD-41

Tuesday, 14:30-16:00 - Virtual Room 41

Crew Planning & Covid

Stream: Timetabling and public transport
Invited session
Chair: *Dennis Huisman*

1 - A Column Generation Approach for the Integrated Crew Re-Planning Problem

Bart van Rossum, Thomas Breugem, Twan Dollevoet, Dennis Huisman

Planned maintenance and construction activities are crucial for heavily used railway networks to cope with the ever increasing demand. These activities lead to changes in the timetable and rolling stock schedule (often for multiple days) and can have a major impact on the crew schedule, as the changes can render many planned duties infeasible. In this paper, we propose a novel integrated approach to crew re-planning, i.e., the construction of new duties and rosters for the employees given changes in the timetable and rolling stock schedule. In current practice, the feasibility of the new rosters is 'assured' by allowing the new duties to deviate only slightly from the original ones. In the Integrated Crew Re-Planning Problem (ICRPP), we loosen this requirement and allow for more flexibility: The ICRPP considers the re-scheduling of crew for multiple days simultaneously, thereby explicitly taking the feasibility of the rosters into account. This way, it can allow for larger deviations from the original duties. We propose a mathematical formulation for the ICRPP, strengthen it using a family of valid cover inequalities, and develop a column generation approach to solve the problem. We apply our solution approach to practical instances from NS, and show the benefits of integrating the re-planning process.

2 - Mathematical Modelling For Tackling Covid19 In Public Transport Networks
Nikola Besinovic

Due to the covid19 crisis, public transport (PT) systems are facing new challenges. Regarding restrictive measures such as physical distancing and the successive returning of passengers after the "intelligent lockdown", significant lack of transport capacity can be expected. In this talk, we tackle emerging problems including transport capacity of a PT network, new transport planning approach and real-time traffic management. We demonstrate these new models on real-life instances. Finally, we outline certain future research directions to undertake against restrictions imposed by covid19.

■ TD-42

Tuesday, 14:30-16:00 - Virtual Room 42

MDPs and related fields

Stream: Stochastic Dynamic Programming
Invited session
Chair: *Odysseas Kanavetas*
Chair: *Flora Spieksma*

1 - Discrete-item Inventory Control involving Fixed Setup Costs, Demand Censoring, and Unknown Distribution
Ehsan Teymourian, Jian Yang, Michael Katehakis

We investigate a dynamic inventory control problem in which orderings involve fixed setup costs and unsatisfied demands are lost. Stepping off from the traditional literature which stresses the randomness of demand realizations, we move on to tolerate ambiguity. Now even the demand distribution f (f(d)_d=0,1,...) itself, out of which random realizations are sampled, can come from a vast and definitely non-singleton set. Lost sales and demand ambiguity would together complicate the problem through censoring, namely, the inability of the firm to observe the lost portion of the demand. Our main policy idea advocates periodically ordering up to seemingly wastefully high levels just to learn and in intervening periods, cleverly exploiting the information gained in these learning periods. By regret, we mean the price paid for ambiguity in long-run average performances. When demand support is unlimited, regret bounds in the orders of O(T8/9) and O(T0.854) can be established for, respectively, the case where f(0) is bounded away from one and the other where the restriction is relaxed with the firm allowed to remove items from the inventory. When demand has a finite support, both bounds could be improved to the order of O(T2/3(ln T)1/2). We also propose other policies. Our simulation demonstrates the merits of the various policy ideas and the hurdles posed by the prospect of f(0) goes to 1−.

2 - Iterative Stochastic Quasigradient procedures for robust estimation, machine learning and decision making problems
Vasyl Gorbachuk, Yurii Ermoliev, Anatoliy Zagorodniy, Vyacheslav Bogdanov, Tatiana Ermolieva, Elena Rovenskaya, Nadejda Komendantova, Olena Borodina, Pavel Knopov, Vladimir Norkin, Alexei Gaivoronski

The talk illustrates the importance of new type non-smooth stochastic optimization and stochastic quasigradient (SQG) procedures for robust of-line and on-line decisions involving large-scale Machine Learning, Distributed Models Linkage, and robust decision-making problems. Advanced robust statistical analysis and machine learning models based on in general nonstationary stochastic optimization allow to account for potential distributional shifts, heavy tails, and nonstationarities in data streams that can mislead traditional statistical and machine learning models, in particular, deep neural learning or deep artificial neural network (ANN). Proposed models and methods rely on probabilistic and non-probabilistic (explicitly given or simulated) distributions combining measures of chances, experts' beliefs and similarity measures (for example, compressed form of the kernel estimators). This is vitally important for integrated sustainable developments modeling. For highly nonconvex models such as the deep ANN network, the SQGs allow to avoid local solutions. In cases of nonstationary data, the SQGs allow for sequential revisions and adaptation of parameters to the changing environment, possibly, based on of-line adaptive simulations. The outlined non-smooth STO approaches and SQG-based procedures are illustrated with examples of robust estimation, machine learning, adaptive Monte Carlo optimization for preventive-adaptive cat risks (floods, epidemics) modeling and management.

3 - Switching curve optimality in two-dimensional queueing control models
Flora Spieksma

Many queueing control models can be modelled as a Markov Decision Process, under suitable conditions on customer arrival and service processes. This allows for applying techniques from this field in order to derive the structure of optimal policies. We will discuss the following two models:

(1) The two-competing queues model with quadratic holding cost per unit time, as a function of the number of customers in each of the queues. (2) The system with two parallel queues and with linear holding cost per unit time and customer, where the controller selects to which queue an arriving customer should be routed optimally.

Numerical results indicate that the optimal policy in both cases is characterised by a linear switching curve, with with slope equal to the ratio of the cost per unit time due to serving one customer type versus serving the other type.

We will discuss the numerical results and provide the theoretical background justifying these.

4 - Asymptotically optimal control for Markov Decision Processes (MDP) under side constraints
Odysseas Kanavetas, Apostolos Burnetas, Michael Katehakis

We consider the problem of adaptive control for Markov Decision Processes (MDP), under side constraints, when there is incomplete information for the transition probabilities and its rewards. Under suitable irreducibility assumptions for the MDP we construct adaptive policies that maximize the rate of convergence of realized rewards to that of the optimal (non adaptive) policy under complete information. We discuss applications and computational results for queuing control problems and contextual bandits.

■ TD-43

Tuesday, 14:30-16:00 - Virtual Room 43

Circular Supply Chains

Stream: Environmental Sustainability in Supply Chains
Invited session
Chair: *Gerald Reiner*

1 - Optimal scavenging and components procurement by an independent remanufacturer - the role of the failure rates and proprietariness of components
Marc Reimann, Rainer Kleber, Joao Quariguasi

According to first hand observations and anecdotal evidence, sourcing replacement parts is no easy task to independent remanufacturers (IRs). When proprietary rights by original equipment manufacturers (OEMs) exist, the price for such parts may be a major barrier for IR operations. A possible remedy IRs find useful is to scavenge parts from collected cores. However, scavenging is not without its challenges. Particularly, whenever a remanufacturer collects a batch of cores to be remanufactured, the number of parts that need replacing is not evenly distributed. In other words, it is typical that specific parts are needed much more often than others, given that there are less of such working parts available among the returned products. In light of those observations we model and analyse an IRs optimal scavenging and procurement decisions of those parts. We find that higher (relative) failure rates of critical parts are not necessarily detrimental to the IR. To better understand this result we also discuss the implications on the IRs optimal collection/remanufacturing decisions. In a second step, we focus on the impact of proprietaryness on these results and find that the key insights are structurally the same. Yet, it always leads to less remanufacturing, while collection may actually increase. Finally, if the OEM indeed pursues planned obsolescence, this may actually be beneficial for the IR and remanufacturing as well as collection may increase.

2 - Supply chain contracts for novel sustainable projects involving multiple firms
Venugopal Ramadasu, Lena Silbermayr, Gerald Reiner

It is identified in various literature and in Sustainable Development Goals that a cross-sectoral collaboration between multiple firms is a key aspect in tackling climate change. Though seen as an important step, a collaboration between multiple-firms with distinctive capabilities in a novel sustainability oriented project is difficult to establish, as it requires close attention to the economic and contractual practices of the partnership. Even with a common project goal, the feasibility and longevity of the collaboration requires a clear agreement on the sharing of costs, revenues, risks, and intellectual property among the involved firms. Often the case with any innovative project, the investments made by the firms in a supply chain are highly uneven in terms of volume. Most of the investments are made by firms in upper tiers of the supply chain, while the firms in the lower tiers accumulate the revenues generated by the sale of the products. Motivated by such a real world three stage supply chain, this research work tries to address the issue of uneven sharing of costs, revenues, and risks in a novel sustainability-oriented project. By considering the need to align the objectives of different players with social preferences (for example fairness concerns), we propose the application of different sustainable supply chain contracts and discuss how they will enable continued collaboration of the firms in the long run.

3 - Improving allocation of service technicians in repair service operations
Gernot Lechner, Sabrina Rosa Rinder, Marc Reimann

Repair is one of the highest value-retention options in a circular economy. However, repair service providers (RSPs) are hard-pressed not only due to intense competition on the repair service market, but consumers often prefer new products over repairing broken items. Thus, RSPs are forced to strive for efficient processes to remain competitive in terms of repair cost and time. Operationally, a crucial factor affecting cost/time is the number of customer visits required by service technicians to complete the repair. For minimizing this number, necessary spare parts must be identified and made available, what is directly related to the quality of information about the defect which is obtained from customers. The information level is influenced by technical capabilities of customers and call center agents, but trained technicians analyzing orders can anticipate needed spare parts and thus, improve the identification efficiency. While an employment of high-paid experts can decrease the number of customer visits, it reduces the available capacity in the field. We analyze this trade-off based on data from a RSP. Given the problem complexity, we apply discrete event simulation for determining the most efficient utilization of service technician capacity. The study results indicate that using technician capacity in the call center indeed positively affects key performance indicators. Our industry partner decided to evaluate the most promising scenario under real-world conditions.

4 - Determining optimal level of circularity for a product with dependent demand
Boualem Rabta

Circular economy is considered as an alternative to the current linear economic model with the ambition to contribute to economic growth in addition to having a positive impact on the environment. Additionally, the supporters of this approach claim multiple business opportunities. For example, capturing additional values from products and materials that are currently discarded as waste. However, there are still challenges for companies to shift their businesses and products into circular practices. Among these, the fear of a negative response from consumers to the inclusion of reused materials / components in the product as shown by recent surveys or that sales of the recirculated product cannibalize those of the new one. In this work, we study the impact of labeling of circular economy products and its use in decision support. In particular, we build a mathematical model taking into account the level of circularity of the product and as well as the behavior of consumers in terms of demand and willingness to pay. The model takes into consideration various forms of the demand function and provides an optimal solution in each case.

■ TD-44

Tuesday, 14:30-16:00 - Virtual Room 44

Inspiring OR

Stream: Practice of OR (Making an Impact)
Invited session
Chair: *Sharon Feely*

1 - Scheduling semiconductor fabrication
Sharon Feely

One of the most complex manufacturing environments is the Wafer fabrication process in the Semi-conductor Industry. Manufacturing cycle times are extending due to the evolution of enhanced products and demand continues to rise. Therefore it is essential to optimise the manufacturing flow at the Wafer fabrication process to minimise cost and meet customer demand on time. This session describes a novel joint venture between Seagate Technology and Flexciton to develop a scheduling model to optimise flow within a Wafer FAB. An overview of the challenges of the current traditional heuristic based scheduling practice, and the challenges of change to successfully deploy a hybrid-optimisation scheduling model will be discussed.

2 - How Discrete Event Simulation can address the consequences of COVID19 pandemic crisis: Practical examples for Operational Research using Simul8
Naoum Tsioptsias

From the beginning of the COVID19 pandemic, a number of papers have addressed the need to use available tools and practices in order to manage the direct and indirect repercussions and consequences of the crisis. Among such tools, the use of Discrete Event Simulation

(DES) within the sectors related to the Operational Research is highlighted. DES has long been established as a viable method for organizations, yet, less work has been able to be attributed to practical cases for countering certain logistic effects of the pandemic. Such examples include supply chain issues, resource availability, testing set-up processes, as well as rule applications for workplaces, public transport and education. Over the past year Simul8 has created relevant examples and participated in Pro Bono projects with the intention to provide access to simulation for organizations confronting the pandemic's consequences. We present here certain sanitized cases from different sectors that Simul8 has worked on to demonstrate how DES can help in reducing and countering the effects of the pandemic: a charity facing resource utilization issues due to reduced personnel, a simulation for a drive-through test station, a return-to-work example for workspace capacity, and an ICU allocation simulation for hospitals. The results show an improvement of throughput despite the different constraints as experimentation with models allows the testing of strategic planning and changes per case.

3 - Using OR to plan quayside operations in real life
Joao Fonseca, Michael Lindahl

About 90% of all goods are transported through a container. The container shipping industry is the back-bone and enabler of global trade, but it is struggling with high cost pressure and low or negative margins. At its core, the industry is inefficient: 50% of all container vessels are delayed coming into port, and key planning processes are done manually on a global scale. This leads to high operational costs, lost revenue, and unnecessarily high greenhouse gas emissions. A huge body of research exists on quayside operations, focused both on richness of models and performance. However, despite the continuous efforts from the academic community to model and solve these problems, most of the main problems related to quayside operations are still solved by hand. At Portchain, we use mathematical modelling and matheuristics to solve Berth Allocation, Quay Crane Assignment, and Quay Crane Scheduling problems in an integrated way. We also developed a user-friendly interface where the user can set parameter values, change port call attributes, and interact with available resources in the terminal. In this talk, we will describe the problems faced by some of our customers, explain why they are mathematically challenging, and provide insights on how we model them. We will finalize the talk with some key results and findings, along with plans to make our tools smarter in the future.

4 - The Fuel Replenishment System implementation
Mikhail Krasilnikov, Aleksejs Lozkins, Ekaterina Kalacheva, Nkolay Rychkov

The Fuel Replenishment System (FRS) consists of oil depots inventory management, vehicle routing of multi-compartment heterogeneous tanker trucks, and tactical fuel replenishment problems. The FRS is developed and integrated into the business processes of one of the largest petrol transportation companies in Russia. The solution system contains a combination of linear programs and heuristics as a continuous pipeline. This software handles 8 regions and 1000 petrol stations, each in a separate process. We present a high-level approach to architecture development. We discuss problems that arise during the implementation of this software, FRS adaptation to real-life, and the study of several practical cases.

■ TD-45

Tuesday, 14:30-16:00 - Virtual Room 45

OR in Manufacturing and Digital Twins 1

Stream: Specific Applications of OR (contributed)
Contributed session
Chair: *Pavlos Eirinakis*

1 - Cognitive Manufacturing: The role of process modelling and optimisation
Nikolaos Sarantinoudis, George Tsinarakis, Kostas Kalaboukas, Pavlos Eirinakis, George Arampatzis

The novel concept of the cognitive factory has been introduced in recent years, in the drive towards the full digitalisation of production lines for the transformation of industry and the realisation of the smart factories of the future. Cyber-Physical Systems, Digital Twins and related digital technologies that build upon the virtualisation of the physical system they support, are at the forefront of research and development. However, applications are yet mostly non-standardised and untested, with uncertain results. The issue of modelling the physical system is crucial in any effort towards this direction. If the cyber system is to display digital cognition capacities, then the physical system's model must support them. However, the meaning and attributes of cognition in this context remain unspecified in most cases. In this paper, a framework for the definition, development and standardisation of cognitive models is described. Cognition is semantically defined as a vector of specific attributes enabled and/or supported by a model. Process modelling is selected as the standard for cognitive models representing production chains. An essential set of model extensions needed for supporting the defined cognitive vector are described at length. The context for practical applications and the operational environment within which the model will interact with other components of a cyber system are also described.

2 - Utilizing an enhanced digital twin to optimize on-specs LPG recovery
Pavlos Eirinakis, George Arampatzis, Aljaž Košmerlj, Jože Rožanec, Nikolaos Sarantinoudis

Liquefied Petroleum Gas (LPG) purification is a complex process involving different types of interconnected process units, encountered in all oil-refinery industries. LPG needs to adhere to certain quality specifications concerning some impurities (e.g., Sulphur, Naphtha and Ethane). However, anomalies that may arise in any given process unit may lead to an off-specs situation, i.e., the LPG in the collection tank may not meet the desired specifications. In such case, actions need to be taken to ensure the final mixture complies with the regulations. We propose a Digital Twin (DT) approach that utilizes Mixed Integer Programming (MIP) to facilitate recovery from such an off-specs situation. DTs offer a virtual environment that may be used to replicate physical processes and allow for the simulation of operations. We implement a DT for LPG production that utilizes machine learning tools to model and simulate the different process units' operations. This DT is enhanced with optimization capabilities triggered to support recovery decisions by indicating which process units need to be utilized and under which operational scenario. The underlying MIP approach drives recovery to on-specs LPG production within a given time horizon while also minimizing the energy consumption.

3 - Scheduling jobs on unrelated machines with job splitting and setup resource constraints
Georgios Zois, Yiannis Mourtos, Stavros Vatikiotis

This work considers the production scheduling of the weaving process in a real-life textile industry, where jobs - each linked to the production of a fabric type and accompanied by a quantity and a priority value - arrive over time and have to be processed (woven) by a set of parallel unrelated machines (looms) with respect to their strict deadlines (delivery dates), under the goal to minimize standard criteria, such as the makespan or the sum of completion times. A number of critical job and machine properties demonstrate the challenging nature of weaving scheduling, i.e., (a) job splitting: each orders' quantity is allowed to be split and processed on multiple machines simultaneously, (b) sequence-dependent setup times: the setup time between any two orders j and k is different than the setup time between jobs k and j on the same machine and (c) setup resource constraints: the number of setups that can be performed simultaneously on different machines is restricted due to a limited number of setup workers. We propose a MILP formulation that captures the entire weaving process. To handle large real instances, while also speeding up an exact solver on smaller ones, we propose two heuristics that perform job-splitting and assignment of jobs to machines either greedily or by using a relaxed version of our MILP model, respectively. We evaluate the impact of our approach on real datasets under user-imposed time limits and resources' (machines, workers) availability.

■ TD-46

Tuesday, 14:30-16:00 - Virtual Room 46

SCM & mobile apps & platforms

Stream: Production and logistics and revenue management (contributed)
Contributed session
Chair: *Tal Avinadav*

1 - The effect of market power structure on a two-platform supply chain when app-quality is co-created
Priel Levy, Tatyana Chernonog

Mobile apps development is a fast growing industry nowadays with Google Play and App Store being the two largest distribution platforms, providing app developers a global coverage of audience. While each platform has its own captive app users, developers have the freedom to distribute their app via either one single platform or both of them. In the latter case, developers should create two versions of the app, differing in their conformance quality (dictated by the platform) but coinciding their design quality (defined by the developer). The innovation of this work lies in considering the co-creation of app quality by the platform and the developer using a revenue-sharing contract, which is popular in the mobile app industry. We analyze a supply chain of mobile apps, in which a strategic developer chooses how to distribute his app—via both platforms or via one of them, so each platform might lose the contract and has a priori to strategize accordingly. Equilibrium analysis is given for two market power structures: horizontal power balance (both platforms simultaneously offer their contract) and horizontal power imbalance (the platform-leader has the right to offer the contract terms first). Several counterintuitive properties of the equilibrium are obtained, in particular regarding the first-move advantage, the mutual effect of the platforms market conditions on the app quality and the conditions under which the developer prefers to distribute his app via a single platform.

2 - Supply chains of mobile apps: Competition, private labels and bypassing when the app's quality is co-created
Tatyana Chernonog

This work deals with issues characterizing the mobile app industry. In particular, we focus on an app developer who competes against either a rival app developer or a private label of the distribution platform, and who can bypass the platform's distribution and billing systems. The innovation of this work lies in considering the co-creation of app quality by the app developer and the distribution platform while using a revenue-sharing contract, which is popular in the mobile app industry. We investigate both tactical equilibrium (the parties' operational decisions for a given market structure) and strategic equilibrium (for the developer — whether or not to bypass; for the platform — whether or not to discourage bypassing by improving the contract terms). Our research provides answers to the following strategic questions: Is it beneficial for the app developer to bypass the distribution platform and offer the app to users directly in a competitive environment? Is it beneficial for the distribution platform to introduce a private label to compete with the app developer? Can bypassing also be beneficial for the platform and/or the rival developer? In response to these questions, several counter-intuitive results are revealed.

3 - Measuring the efficiency of retailers' online platforms in integrating physical and digital operations during the pandemic: A Slack-Based Measure approach
Tatiana Kodama, Isotilia Costa Melo, Paulo Nocera Alves Junior, Karoline Silva, Jéssica Syrio Callefi, Karine Borri, Daisy Rebelatto, Marcelo Nagano

The COVID-19 pandemic imposed lockdowns and accelerated the digitalization in physical retailing (business-to-customer) worldwide. Here is proposed a method for evaluating the management efficiency of retailers' online platforms in integrating physical and digital operations. The mathematical model is the Slack-Based Measure (SBM) - Data Envelopment Analysis (DEA), followed by the sensitivity analysis of SBM Super-Efficiency. Each retailer's online platform is considered a unit of analysis of the model (Decision-Making of Unit - DMU). The DMU's relative efficiency is measured based on the capacity in transforming digital accesses and lean-based variables, such as slacks of inventory and capacity (i.e., exceeding inventory and physical infrastructure), in operational gross margin. The method was applied to 36 online platforms, controlled by 13 retailer networks, considering the last quarter of 2020 in the Brazilian market. The main results encompass a rank of relative performance, pointing out the benchmarks. The findings also showed that, whether the strategy is not integrative, operating many platforms not necessarily imply a better performance than operating a unique platform. The proposed method can be replicated in other markets and periods (e.g., before and after pandemic), which is useful for practitioners to understand the relative performance among competitors as well as for policy-makers interested in fostering digitalization and/or economic recovery.

4 - The effect of risk aversion on a supply chain of in-app products when freemium business model is applied
Tal Avinadav, Eyal Bunker

This work studies the decisions of a platform and an app developer who interact via a revenue sharing contract under a freemium-app business model with optional in-app purchases. We consider random quality, according to which the developer invests to obtain a target quality level but the actual level may deviate from his goal. We conduct our analysis under the mean-variance framework and include two financing schemes for the developer investment in quality: self-financing, and being financed by an investor in exchange for a certain share of his future revenues. Our main findings are: (i) the stochastic dominance property exists both for the platform's and the investor's profits with regard to their revenue shares; (ii) the more risk averse the developer is, the more he tends to use a revenue-based financing method, but he will receive a lower financing amount, and (iii) the shift from self-financing to revenue-based financing lowers the platform's expected revenue

■ TD-47

Tuesday, 14:30-16:00 - Virtual Room 47

Mixed-Integer Bilevel Optimization

Stream: Mixed-Integer Nonlinear Optimization
Invited session
Chair: *Ivana Ljubic*

1 - A branch-and-cut algorithm for submodular interdiction games
Kübra Tanınmış, Markus Sinnl

In this talk, we address zero-sum Interdiction Games where the objective is a monotone and submodular set function. Given a ground set of items, the leader interdicts the usage of some of the items by the follower who seeks to maximize a submodular set function over the uninterdicted items. This class of problems finds a wide range of applications including the interdiction versions of maximal covering, facility location, bipartite inference, concave utility function maximization, and assortment optimization problems, in addition to the problems with a linear objective function such as knapsack interdiction. We propose new submodular interdiction cuts and design a branch-and-cut algorithm based on them. We also present extensions and liftings of these cuts. We test our solution framework on several applications under multiple settings. For all applications, the improved variants of the submodular interdiction cut perform significantly better than its basic version. For the maximal covering interdiction problem for which a mixed-integer bilevel linear programming (MIBLP) formulation is available, we compare the results with those of a state-of-the-art MIBLP solver. While the MIBLP solver yields a minimum of 54% optimality gap within one hour, our best branch-and-cut setting solves all but 4 of 216 instances optimally with a maximum of 5% gap among unsolved ones.

2 - The Edge Interdiction Clique Problem
Ivana Ljubic, Fabio Furini, Pablo San Segundo, Yanlu Zhao

Given a graph G and an interdiction budget k, the Edge Interdiction Clique Problem (EICP) asks to find a subset of at most k edges to remove from G so that the size of the maximum clique, in the interdicted graph, is minimized. The EICP belongs to the family of interdiction problems with the aim of reducing the clique number of the graph. The EICP optimal solutions, called optimal interdiction policies, determine the subset of most vital edges of a graph which are crucial for preserving its clique number. We study the problem from the bilevel perspective, and propose a new set-covering-based Integer Linear Programming (ILP) formulation for the EICP with an exponential number of constraints, called the clique-covering inequalities. Extensive tests show that the new exact algorithm greatly outperforms the state-of-the-art approaches for the ECIP.

3 - Outer Approximation for Global Optimization of Mixed-Integer Quadratic Bilevel Problems
Martin Schmidt, Thomas Kleinert, Veronika Grimm

Bilevel optimization problems have received a lot of attention in the last years and decades. Besides numerous theoretical developments there also evolved novel solution algorithms for mixed-integer linear bilevel problems and the most recent algorithms use branch-and-cut techniques from mixed-integer programming that are especially tailored for the bilevel context. In this talk, we consider MIQP-QP bilevel problems, i.e., models with a mixed-integer convex-quadratic upper level and a continuous convex-quadratic lower level. This setting allows for a strong-duality-based transformation of the lower level which yields, in general, an equivalent nonconvex single-level reformulation of the original bilevel problem. Under reasonable assumptions, we can derive both a multi- and a single-tree outer-approximation-based cutting-plane algorithm. We show finite termination and correctness of both methods and present extensive numerical results that illustrate the applicability of the approaches. It turns out that the proposed methods are capable of solving bilevel instances with several thousand variables and constraints and significantly outperform classical solution approaches.

4 - Solution methods using n-ary branching, column generation and cutting planes for a Mixed Integer Nonlinear Bilevel Optimisation Problem
Karl-Matthias Steinborn-Busse

Bilevel optimisation is a variant of mathematical programming, where a subset of variables are constrained to being the optimal solution of another optimisation problem. We focus our attention to a bilevel pricing problem, where the follower aims to purchase a set of commodities, which must satisfy some combinatorial constraints, in the cheapest manor possible, with the leader able to add a taxation to any commodity that they have bought themselves. In this problem, the followers problem is purely integer and has a feasible region independent of the leaders variables, with the nonlinear terms appearing the both the ledaers and followers objective functions only. We present solutions methods that are based around solving the High Point Relaxation by using cutting planes, column generation and n-ary branching techniques, along with a further method, that takes advantage of the leader knowing a subset of follower feasible solutions, which can be used in conjunction with the solution methods just described.

■ TD-48

Tuesday, 14:30-16:00 - Virtual Room 48

Production planning and Lot-sizing

Stream: Lot Sizing, Lot Scheduling and Production Planning
Invited session
Chair: *Safia Kedad-Sidhoum*
Chair: *Paula Metzker Soares*

1 - Production planning with returns, refurbishing and downward substitution
Nadjib Brahimi, Youcef Boutarfa, Ahmed Senoussi

In this work, we consider a production planning problem with returns and possible substitution between new and refurbished items. After the return process, items are either refurbished or dismantled in order to use their useful parts. These parts are remanufactured so that they become as good as new. They will be used in the assembly of new finished products. The latter can also use new components purchased from external suppliers. On the other hand, products accepted for refurbishing undergo a set of operations and are sold as second hand products. We allow one way downward substitution. That is, if there is a shortage of refurbished products, demand can be satisfied using new products without any price increase. The objective is to minimize total cost composed of setup costs at the different stages of the process, inventory holding costs, and purchasing cost of new components. This problem is NP-hard. Initially, it is formulated as a MILP and solved using a commercial MILP solver which was unable to solve average size instances in a reasonable amount of time. Hence, we propose a relax-and-fix heuristic whose results are much better than the use of the solver on the original model. In addition to that, the heuristic allows the practitioners to choose between higher quality solutions at longer processing times or shorter processing times but with a rather medium quality solution.

2 - New construction heuristics and metaheuristic for lot-sizing problems
Daryna Dziuba, Christian Almeder

We consider the classical capacitated lot-sizing problem which is known to be NP-hard. Several construction heuristics have been proposed in the research literature, but none of them is convincing in terms of solution quality and generality - meaning that they can be applied to different variations of the problem. We propose a general greedy construction heuristic (GCH), extended with local search, and embed it into a GRASP metaheuristic. First experiments on the single-level capacitated lot-sizing problem (CLSP) deliver promising results, meaning that we are able to find optimal solutions for some instances and in general the gap to best solutions found by a MIP-solver is 4,7% using only GCH, 3,4% using GCH and local search and 0,6% on average using GCH within GRASP framework. The heuristic can easily be extended to handle cases with setup times and multi-level product structures.

3 - An adaptive robust approximation for the lot-sizing problem under yield uncertainty
Paula Metzker Soares, Alexandre Dolgui, Yossiri Adulyasak, Simon Thevenin

This work addresses the multi-period single-item lot-sizing problem with backlog under yield uncertainty via the robust optimization methodology. We study a linear approximation of the adaptive robust LSP model, which ignores the quadratic term that makes the model difficult to solve. Besides, we provide some analytical insights regarding the properties of the optimal adaptive robust solution. In the light of the adaptive robust approximation, we demonstrate the effectiveness of the robust methodology to mitigate the uncertainties and reduce the impact of the occurrence of uncertain features on the decisions even if few information about the uncertainty is known. The ARO approximation achieves to the minimization of costs, and meet demands efficiently and with good quality products. Numerical experiments demonstrate that the adaptive model can outperform the static model, while marginal additional computational effort is required to obtain a good robust production plan. The results also indicate that the proposed approach is a good alternative for a system that is flexible for changes in the production quantity in each period. Therefore, we can conclude that the approximated adaptive robust approach achieves satisfactory results that are free of strong assumptions about the disturbance in the worst case scenario, even if only a partial perspective of the robustness of the optimal solution is addressed by our approximated model.

■ TD-49

Tuesday, 14:30-16:00 - Virtual Room 49

Expasion planning problems in renewable-dominated power systems (online)

Stream: Emerging technical and financial aspects of energy problems
Invited session
Chair: *Luis Baringo*
Chair: *Álvaro García-Cerezo*

1 - Learning-based Coordination of Transmission and Distribution Operations
Salvador Pineda Morente, Juan Miguel Morales, Yury Dvorkin

This paper proposes a learning-based approach for the coordination of transmission and distribution operations. Given a series of observations of the nodal price and the power intake at the main substation of a distribution grid, we construct the nonincreasing piecewise constant function that best explains the response of the grid to the electricity price. In order to captures changes in this response, we make the inference process conditional on some easily accessible contextual information. The learning task can be carried out in a computationally efficient manner and the curve it produces can be naturally interpreted as a market bid whereby the distributed energy resources in the grid can directly participate in the wholesale electricity markets, thus averting the need to revise the current operational procedures for the transmission network. We consider a realistic case study to compare our approach with alternative ones, including a fully centralized coordination of transmission and distribution, for different levels of grid congestion at distribution.

2 - Mathematical modelling for the long-term energy planning; Case study: The Greek electrical energy system 2020-2050
John Coletsos, Nicky Katoufa, Dimitris Stogiannis

In a continuously evolving energy environment, the need to adopt efficient national energy policies is imperative. The main guidelines of successful energy strategies include the security of energy supply, the effective management of the environmental crisis, and the assurance of sustainable development for the entire energy system.

To deal with issues like the world economic growth, demographic evolution, the increasing energy demand, environmental deterioration, climatic change, the shrinking of available energy resources, and the recent pandemic, an effective nationwide long-term energy planning is required.

To design an optimal national energy production strategy is a challenging problem as it uses multiple decision criteria and contains a high degree of complexity due to the large number of available energy production technologies, the diversity of energy resources, the volatility of demand, the variety of funding sources, the environmental impact, etc.

The present paper focuses on the electricity production sector, which is the most impactful aspect of the entire energy chain. We present a mixed-integer linear programming model to optimize the long-term energy planning for the development of the electricity production system in Greece, defining the best combination of electric energy forms and technologies used to cover the electricity demand for the years 2020 to 2050, taking into account the technical, economic, environmental, and regulating restrictions.

3 - A robust structural electric system model with significant share of intermittent renewables under autocorrelated residual demand
Pierre Cayet

In this paper, we propose a robust structural investment and dispatch model of electric systems including commitment and storage constraints under auto-correlated residual demand. We associate it to a novel approach to robust optimization focusing on uncertain parameter trajectories. Using Principal Component Analysis, we approximate conditional order statistics for the differential distribution of components of residual demand using parametric polynomial approximation. This flexible method allows us to derive a set of extreme trajectories maximizing the level and variability of residual demand. Finally, we apply our dynamic robust model to the electric system of the French region Auvergne Rhône-Alpes and discuss the implications in terms of investment decisions and cost performance.

4 - A risk-averse two-stage stochastic approach for the transmission network expansion planning problem considering long- and short-term uncertainty
Álvaro García-Cerezo, Raquel García-Bertrand, Luis Baringo

This paper proposes a risk-averse two-stage stochastic approach for the transmission network expansion planning problem, in which the conditional value-at-risk of the operating costs is used as a risk measure. The problem is formulated as a mixed-integer linear programming under the perspective of the transmission system operator, whose aim is to identify the building of transmission lines that minimize both investment and operating costs. We model long-term uncertainty of the peak demand levels and the operation cost coefficient of conventional generating units through a discrete set of scenarios. The main drawback of the traditional formulation of this problem is that a large number of scenarios is required to accurately represent the uncertainty in these parameters, which leads to problems of computational intractability. Hence, we propose using a constraint generation based algorithm to reduce the computational time of the problem. In addition, a modified version of the maximum dissimilarity algorithm and the chronological time-period clustering are combined to model the short-term uncertainty of demand and solar- and wind-power production using representative days. The performance of the proposed model and the traditional formulation of the problem are compared using the IEEE RTS 24-bus test system.

■ TD-50

Tuesday, 14:30-16:00 - Virtual Room 50

AI4RAILS V

Stream: The 2nd International Workshop on Artificial Intelligence for RAILwayS (AI4RAILS)
Invited session
Chair: *Zhiyuan Lin*

1 - Vision-based railway track extraction and obstacle detection using deep learning for autonomous train
Amine Boussik, Antoine Plissonneau, Wael Ben Messaoud, Abdelmalik Taleb-Ahmed, Smail Niar, Abdelghani Bekrar, Damien Trentesaux

Obstacle detection is a critical and necessary task for the proper functioning of driverless vehicles. Autonomous driving is a very active field of research, particularly in the automobile industry. However, very few works have been realized for railways obstacle detection especially when it comes to machine learning-based methods, this is often the case because the data is not readily available or the classes for the obstacles are not known beforehand. In this paper, we propose a framework to detect obstacles for autonomous trains using deep learning methods trained on frontal ego-perspective acquisitions of the train. Using normal railways scene images, we aim to exploit deep learning methods to detect obstacles as anomalies on the main rail track. In our approach, we do not assume any prior knowledge of the obstacles' classes by using unsupervised learning. Our contribution is threefold: First, we propose an algorithm to detect and localize all rails in input images. Second, we propose a pipeline based on clustering on the previously detected rails to extract, in real-time, the region of interest i.e the main rail track. Third, in order to detect obstacles, we propose a convolutional auto-encoder based method to process the aforementioned regions of interest. Our framework was tested and validated on railway scenes consisting of a mixture of inlaid obstacles and real-world scenarios containing real obstacles.

2 - Degradation modeling of railway tracks by analysing longitudinal level change with machine learning techniques
Nadine Friesen, Saskia Bluhm, Nils Nießen

With the aim of finding optimal maintenance strategies, railway infrastructure companies face the challenge of describing the relationship between maintenance costs and the quality of the infrastructure. In this context, it is necessary to predict the effect of maintenance activities as well as the degradation process of infrastructure items with and without maintenance. In this paper we focus on modelling the deterioration of railway tracks. To predict their degradation process, we use continuous track monitoring (CTM) data where the longitudinal level change of railway tracks is measured several times a week by regular trains on selected lines. Those CTM data sets contain data of tracks where conducted maintenance measures are included. To obtain time series where no maintenance measures were performed, we present an approach to automatically identify the time points where maintenance has been performed and extract the time series between maintenance measures. We model the degradation of tracks and analyse the influence of factors such as velocity, load, radius or sleeper type on the rate of the deterioration by applying decision trees, neural networks and similarity models to the longitudinal level change. The different approaches are compared. In contrast to currently used expert-based approaches the use of these machine learning models leads to a more precise and deeper understanding of the degradation process to improve maintenance planning for railway tra

3 - Artificial Intelligence in railway transport: the state-of-the-art survey and future research agenda
Ruifan Tang, Lorenzo De Donato, Nikola Besinovic, Francesco Flammini, Zhiyuan Lin, Ronghui Liu, Mauro José Pappaterra, Tianli Tang, Valeria Vittorini, Ziyulong Wang

Nowadays it is widely accepted that Artificial Intelligence (AI) is significantly influencing the operations in many domains, including railways. In this talk, we present a systematic literature review of the current state-of-the-art of AI in railway transport. In particular, we analysed and discussed papers from a holistic railway perspective, covering subdomains such as maintenance and inspection, transport planning and management, safety and security, autonomous driving and control, revenue management, transport policy, and passenger mobility. This review makes an initial step towards shaping the role of AI in future railways and provides a summary of the current focus of AI research connected to rail transport. We reviewed about 120 scientific papers covering the period from 2010 to August 2020. We found that the major research efforts have been put in AI for rail maintenance and inspection, while very limited or no research has been found on AI for rail transport policy and revenue management. The remaining subdomains received mild to moderate attention. AI applications are promising and tend to act as a game-changer in tackling multiple railway challenges. However, at the moment, AI research in railways is still mostly at its early stages. Future research can be expected towards developing advanced combined AI applications (e.g. with optimisation), using AI in decision making, dealing with uncertainty, and tackling newly rising cybersecurity challenges.

4 - Mountain Railway Alignment Optimization with Deep Reinforcement Learning
Qing He, Tianci Gao

The design and planning of railway alignments is the dominant task in railway construction. However, it is difficult to achieve self-learning and learning from human experience with manual as well as automated design methods. Also, many existing approaches require predefined numbers of horizontal points of intersection (HPIs) or vertical points of intersection (VPIs) as input. To address these issues, this study employs deep reinforcement learning (DRL) to optimize mountainous railway alignments with the goal of minimizing construction costs. First, in the DRL model, the state of the railway alignment optimization environment is determined, and the action and reward function of the optimization agent are defined along with the corresponding alignment constraints. Second, we integrate a recent DRL algorithm called the deep deterministic policy gradient (DDPG) with optional human experience to obtain the final optimized railway alignment, and the influence of human experience is demonstrated through a sensitivity analysis. Finally, this methodology is applied to a real-world case study in a mountainous region, and the results verify that the DRL approach used here can automatically explore and optimize the railway alignment, decreasing the construction cost by 17.65% compared with the manual alignment and by 7.98% compared with the results of a method based on the distance transform while satisfying various alignment constraints.

■ TD-51

Tuesday, 14:30-16:00 - Virtual Room 51

OR in Aviation 3

Stream: OR in Aviation
Invited session
Chair: *Thomas Hagspihl*

1 - A cooperative multi-agent airline planning framework
Mahdi Noorafza, Bruno Filipe Santos, Alexei Sharpanskykh

Airline operation consists of multi-scale inter-related decisions concerning planning and scheduling at strategic, tactical and operational levels. Taking into account the real size problem, solving a monolithic airline operation problem is believed to be computationally intractable. Airlines usually decompose their entire planning scheme into several isolated sub-problems to overcome the curse of dimensionality. Such a decomposition could lead to sub-optimal solutions and neglecting crucial inter-dependencies. In this research, we developed a novel multi-agent framework to model the dependencies in this decision field. Our framework primarily has a threefold contribution. First, it captures inter-dependencies among multiple sub-problems. Secondly, it can maintain well-balanced framework scalability and final solution quality thanks to the proposed agent-based version of the rolling horizon algorithm. Finally, it could be used as a what-if scenario testbed to evaluate new technology's adaption consequences. In our proposed framework, specialised agents are responsible for collaboratively solving each sub-problem. They will form all blocks of airline operation plan through a collaborative planning process. As proof of concept, we implemented our framework's strategic planning module responsible for optimising airline long-term decisions. It shows better scalability compared to an equivalent extensive mixed-integer model while maintains a reasonable solution quality.

2 - Crew Recovery Using Machine Learning and Optimization
Vikrant Vaze, Esat Hizir, Cynthia Barnhart

Due to the irregular nature of flight operations, airlines need to take a range of actions to recover their aircraft and crew schedules. While recovery problems are smaller in scope than their planning counterparts, limited time frames prevent airlines from using a full-scale optimization approach. Consequently, airlines usually adopt manual solution approaches using decision support systems. This study proposes a set of new and practical ideas that combine Machine Learning (ML) and optimization tools to find near optimal solutions for the crew recovery problem within the limited time frames. Our experiments show that ML can be used to accelerate crew recovery optimization significantly while keeping the solution quality close to the optimal. The developed procedure is based on the idea that the most effective cuts (constraints) to add to the solution space can be determined by leveraging the similarities between disruptions with the help of ML tools. Offline preparation phase consists of database generation, in which real and synthetic disruption scenarios are solved to a target optimality and ML training, in which a set of prediction models are trained using the solutions database. The resulting models help to reduce the size of the solution space before the actual optimization. The experiments showed that in the case of limited preparation time, it is possible to use lower quality solutions for database generation without affecting the overall performance significantly.

3 - Dynamic Gate Configurations at Airports: A Network Optimization Approach
Thomas Hagspihl, Rainer Kolisch, Christian Ruf, Sebastian Schiffels

We consider the configuration of airport gates with passenger boarding bridges. The set of aircraft types that can be serviced at a gate depends on the installed boarding bridge(s). For instance, the Airbus A380 can only be serviced at gates equipped with a passenger boarding bridge that is able to access its upper level. Given the dynamic development of both the number of aircraft movements and the fleet mix at airports, the recurring decision problem is to determine for each gate whether and when the passenger boarding bridge configuration should be changed. The objective is to minimize investment and operating costs associated with the bridges as well as penalty costs for aircraft which cannot be processed because gates that are equipped with adequate gate configurations are not available. We propose a mixed-integer model formulation and present its underlying network structure. To solve the problem, we employ a column generation based heuristic approach. We demonstrate the good performance of the heuristic in a computational study and present a detailed discussion of the decisions taken as part of a case study.

■ TD-52

Tuesday, 14:30-16:00 - Virtual Room 52

Energy, Industry and Transport

Stream: OR in Climate Policy and Planning
Invited session
Chair: *Haris Doukas*
Chair: *Emilia Kondili*

1 - Shutting off the proverbial oil valve
Marius Stenersen, Mo Mansouri

The planet we live on is undergoing changes we have never witnessed or documented before, man-made or not. Petitions are made to stop the activity of extracting petroleum as it is considered a main contributor of Greenhouse gas emissions. Though the petitions presents mathematical models on the negative impact of continuing this road, they do not inform that petroleum is a versatile product, and how it can be replaced. This paper is written to show in a very few pages how complex the petroleum industry is, how everything is connected and why it is not so easy to stop extracting and using it.

2 - Managing public EV charging station availability with data-driven strategies
Christos Stefanatos, Eleni Kanellou, Vangelis Marinakis, Haris Doukas

Charging sessions of battery electric vehicles (BEV) require significantly more time in comparison to refueling of conventional internal combustion engine vehicles (ICE). Charging a modern BEV from 10% - 90% requires 6 hours in Alternating Current charging stations and 40 minutes on average for Direct Current (DC) charging stations. As adoption of electric vehicles broadens in European Union, managing availability of charging stations emerges as a critical challenge. This challenge is especially relevant for public charging stations adjacent to National Highways or in busy destinations such as hotels. This work aims to identify a methodology to extrapolate the occupancy of charging stations given historical data for the specific charging station and anticipated increase of EV traffic in the vicinity. Data from 18 public charging stations in Greece and Hungary, obtained from charge point platform EV Loader and open data repositories are analyzed. To extrapolate station occupancy in the future, anticipated increases in the number of electric vehicles in Greece and Hungary are considered, based on the respective National Energy and Climate Plan (NECP) forecast data for each country. Through this analysis specific charging stations expected to face availability and long wait times in the future are identified and additions in the number of plugs and/or charging capacity on a case-by-case basis are proposed.

3 - Machine Learning Approaches to Load Factor Management for Energy Demand and Supply Capabilities
Charity Delmus Alupo, Paula Carroll, Eleni Mangina

Uganda, like many sub-Saharan African countries, faces a significant challenge in meeting energy demand. Electricity contributes only 1.1% to the national energy balance with hydropower being the primary source of generation, supplying power for residential, commercial, industrial and other uses. Frequent load shedding occurs when supply cannot meet demand. There is a need to manage the electricity generated more efficiently for continuity in supply, and better utilisation of installed infrastructure.

Load factor management is a great opportunity for Uganda to handle its electricity deficits. A load factor is defined as the ratio of the average load over a given period to the peak load in that period. In Uganda, the demand generally has peaky trends because of high demand for lighting at dusk. This means that many consumers are utilising electricity at specific periods of the day, consequently affecting the supply capabilities of the grid. Using data from the Irish Smart Metering Electricity Customer Behaviour Trials, this study aims to experiment with various load factor modelling techniques using machine learning models and data analytics. We explore if incorporating Time of Use into the customer clusters (consumers with similar behavioural traits) can influence the load factors and on-peak demand. Load factor models developed during this study will be further applied to Ugandan data for similar studies.

4 - Can resource classes substitute spatial resolution in energy system models? A spatial scaling analysis.
Kai von Krbek

While regional aggregation of areas can increase the computation speed of energy system models (ESM), this can also lead to an underestimation of the localised high quality of variable renewable energy (VRE) sources, which vary strongly depending on the site. Partly, the power transmission grid is able to level out the locality of production and consumption with energy systems spanning across regions as far as the European continent with large amount of power traded, which leads to a spatial averaging of the feed in profiles. Resource classes can subdivide VRE potentials into different quality classes of distinct feed-in profiles and potentials to compensate for the coarser resolution of the aggregated regions. This will lead to higher full load hours for the better located VRE power plants and thus lower levelised costs of electricity for those plants.

This talk will examine the trade-offs between a high spatial resolution on the one hand and the accuracy of the feed in of VRE sources on the other hand. Therein the focus lies on the dispatch and expansion of the different technologies. The investigation focusses on wind resource classes, since wind speeds vary much more spatially than solar irradiance. Germany has been chosen for this investigation as its wind resource is diverse: the flatt northern parts offer high wind potentials whereas the resource quality in the south is much more dependent on the local topology.

■ TD-53

Tuesday, 14:30-16:00 - Virtual Room 53

Modelling tools I

Stream: Software for Optimization
Invited session
Chair: *Susanne Heipcke*

1 - OR-Tools
Pawel Lichocki

OR-Tools is a mature, open source software suite for combinatorial optimization, tuned for tackling the world's toughest problems in i) integer and linear programming, ii) satisfiability and constraint programming, iii) vehicle routing and iv) graph flows. In this talk, we explain how to use OR-tools in each of these four categories by presenting several short and vivid examples. Along the way, we present the available modeling primitives, like the supported types of constraints. And, we briefly discuss the algorithms and solvers implemented under the hood, like the award-winning CP-SAT solver. OR-Tools is implemented in C++ for efficiency, and it also exposes APIs in Python, Java, and C#. Overall, we believe that the diversity of the supported optimization approaches and programming languages, as well as the high quality of the implementation, makes OR-Tools the best, one-stop solution for many academic and industrial applications.

2 - New mathematical modeling constructs in Xpress Mosel
Susanne Heipcke, Yves Colombani

Mathematical optimization models often contain inherently nonlinear constructs, such as absolute values or logical relations. A widely used approach to handle such cases consists in linearizing the nonlinear expressions to make the model suitable for solving via a MIP solver. Recent releases of FICO Xpress introduce new modeling constructs in Mosel that allow for an easier formulation of MIP models that contain certain logical or nonlinear constraints without the need for explicit linear reformulations. These new genuinely nonlinear constructs (piecewise linear expressions; absolute value, minimum value, maximum value of discrete or continuous decision variables; logical constraints 'and', 'or', 'not' over Boolean variables) are handled directly by the Xpress MIP solver that can thus exploit the structure for efficient handling of these relations when solving the problem. This talk discusses formulation alternatives for MIP models implemented with Mosel. We shall also touch on other new features in Mosel that are relevant to the implementation of optimization models, such as improved matrix handling and access features, and enhanced support for the implementation of multi-threaded algorithms via cloning of submodels and the possibility of sharing data between cloned models.

3 - New Connections to the AMPL Modeling Language: Spreadsheets and Callbacks
Robert Fourer

Optimization applications are often concerned as much with making connections as with building models. This presentation describes two connections recently implemented in the AMPL modeling language and system. A direct spreadsheet connection reads and writes xlsx-format files, defining correspondences between common spreadsheet layouts and AMPL's algebraic data definitions. Support is included for "two-dimensional" spreadsheet tables in which one index labels the columns and one or more indices label the rows. A solver callback connection enables AMPL's APIs to communicate with algorithms as they are running, uniting the ease of modeling in AMPL with the flexibility of programming to customize algorithmic behavior. This facility can be used to write specialized routines that report progress, change settings, and generate constraints that cut off fractional solutions.

4 - Recent Updates to Optimization Modeling in MATLAB
Paul Kerr-Delworth, Aurele Turnes, Mary Fenelon

The problem-based workflow for optimization problems makes it much easier to model and solve such problems in MATLAB. First, optimization variables are identified and defined. Next, familiar MATLAB operators can be used to define the objective and constraints as expressions of the optimization variables. The optimization solver is then selected automatically based on the type of constraints and objective. Large and complex optimization models can be expressed compactly using MATLAB arrays of optimization variables and expressions, indexing with either numbers or strings.

An overview of the problem-based workflow will be presented, highlighting new capabilities including automatic differentiation and least squares problem support.

■ TD-54

Tuesday, 14:30-16:00 - Virtual Room 54

Data Science and Analytics - Methodology II

Stream: Data Science and Analytics (contributed)
Contributed session
Chair: *Annabella Astorino*

1 - Solving the Knapsack Problem Using Reinforcement Learning Techniques
Samuel Benford, Mohammad Dehghani

The knapsack problem (KP) is a common optimization problem within the field of operations research. Within this study, we tested the viability and effectiveness of the use of Reinforcement Learning (RL) algorithms to solve the KP. Multiple experiments were run to test performance of different Tabular RL and Deep RL methods and compare them with each other as well as the exact-solution DP method and metaheuristics algorithms. Results show that RL methods were able to adapt to the change in the size of the problem well and required only minor tuning to hyperparameters. Within the RL category, the best overall performer was the Double Deep Q-Network (DDQN) algorithm which utilizes two neural networks to estimate the value of each action. This algorithm was able to achieve the highest total value in the knapsack for the most experiment scenarios (including metaheuristic algorithms).

2 - Dynamic L1 Regression
Botan Citil

L1 regression has several advantages over ordinary least squares. One is its "robustness" i.e., relatively insensitivity to outliers in the data. Unlike OLS, L1 regression does not have a closed-form solution, requiring instead formulating and solving a linear program. Modern data environments are hardly ever static and in reality, highly dynamic. Again, unlike OLS, L1 regression is largely unexplored topic in a dynamic streaming data environment. It requires re-solving linear programs on the fly. We present results on efficient ways to perform L1 regression analysis as the model accrues data points.

3 - A multi-sphere approach for Multiple Instance Learning classification
Matteo Avolio, Annabella Astorino, Antonio Fuduli

Multiple Instance Learning (MIL) consists in classifying bags of instances. The main characteristic of a MIL problem is that, in the learning phase, only the labels of the bags are known, while the labels of the instances belonging to the bags are unknown. In the case of two types of instances and two types of bags (positive and negative), a very common assumption consists in considering a bag positive if it contains at least a positive instance and negative if it contains only negative instances. Starting from this assumption and initially inspired by a well-established SVM type approach, we present a spherical based instance-space algorithm where a finite and variable number of spheres is generated using the following criterion: a bag is considered positive if at least one of its instances belongs to the union of the spheres (i.e. it is contained in at least a sphere) and it is negative if all its instances are outside the union of the spheres (i.e. they are not contained in any sphere). Numerical results are presented on a set of benchmark datasets.

4 - Multiple Instance Learning by Polyhedral Approaches
Annabella Astorino, Matteo Avolio, Antonio Fuduli

Multiple Instance Learning (MIL) is a variant of traditional supervised learning that has received a considerable amount of attention due to its applicability to real-world problems such as drug activity prediction and image classification. In particular, we are interested in the binary classification case where the objective is to construct a classifier on the basis of positive and negative training examples. The main difference with the traditional supervised learning scenario is in the nature of the learning examples. In fact, each example is not represented by a fixed-length vector of features but by a bag of feature vectors that are referred to as instances. The classification labels are only provided for entire training bags whereas the labels of the instances inside them are unknown. The task is to learn a model that predicts the labels of the new incoming bags together the labels of the instances inside them. In this work we tackle the MIL problem by polyhedral approaches. The idea is to generate a polyhedral separation surface characterized by a finite number of hyperplanes such that, for each positive bag, at least one of its instances is inside the polyhedron and all the instances of each negative bag are outside. We come out with nonlinear nonconvex nonsmooth optimization problems of DC (Difference of Convex) type that we solve by adapting the DCA algorithm. The results of our implementation on a number of benchmark classification datasets are presented.

■ TD-55

Tuesday, 14:30-16:00 - Virtual Room 55

Data Science and Optimization

Stream: EURO Working Group Data Science meets Optimisation
Invited session
Chair: *Patrick De Causmaecker*
Chair: *Daniel Karapetyan*
Chair: *Ender Özcan*

1 - Democratising Constraint Satisfaction Problems through Machine Learning
Mohit Kumar, Samuel Kolb, Clement Gautrais, Luc De Raedt

Constraint satisfaction problems (CSPs) are used widely, especially in the field of operations research, to model various real world problems like scheduling or planning. However, modelling a problem as a CSP is not trivial, it is labour intensive and requires both modelling and domain expertise. The emerging field of constraint learning deals with this problem by automatically learning constraints from a given dataset. While there are several interesting approaches for constraint learning, these works are hard to access for a non-expert user. Furthermore, different approaches have different underlying formalism and require different setups before they can be used. In this work we combine these researches and bring it to non-expert users in the form of an interactive Excel plugin. To do this, we translate different formalism for specifying CSPs into a common language, which allows multiple constraint learners to coexist, making this plugin more powerful than individual constraint learners. Moreover, we integrate learning of CSPs from data with solving them, making it a self sufficient plugin. For the developers of different constraint learners, we provide an API that can be used to integrate their work with this plugin by implementing a handful of functions.

2 - Using the Proximal Policy Optimization Algorithm for Solving the Stochastic Capacitated Lot Sizing Problem
Lotte van Hezewijk, Nico Dellaert, Tom van Woensel, Noud Gademann

We study the multi-item stochastic capacitated lot-sizing problem to minimize setup, holding, and backorder costs. This is a common problem in the industry, concerning both inventory management and production planning. We study the applicability of the Proximal Policy Optimization (PPO) algorithm in this problem, which is a type of Deep Reinforcement Learning (DRL). The problem is modeled as a Markov Decision Process (MDP), which can be solved to optimality in small instances by using Dynamic Programming. In these settings, we show that the performance of PPO approaches the optimal solution. For larger problem instances with increasing demand and more products, solving to optimality is intractable, and we show that the PPO solution outperforms the benchmark solution. We also investigate the limits of PPO in terms of problem size and suggest adjustments that could improve the applicability of PPO in more extensive problems.

3 - The Hyperparameter Optimization Problem in Matrix Factorization
Laura Selicato, Flavia Esposito, Nicoletta Del Buono

Research in automatic learning focuses on developing methods capable of extracting useful information from a given dataset. A wide variety of learning methods exist, ranging from biologically inspired to statistical methods. A common feature of these methods is that they are parameterized by a set of hyperparameters (HPs) that must be tune appropriately by the user to maximize the utility of the learning approach. Matrix Factorizations (MFs) have been used in recent years to reconstruct a given data matrix. These techniques gained much more attention with data mining applications trying to capture the information embedded in large datasets. MFs aim at providing information that cannot be directly identified from the original dataset by reducing it to a low-dimensional space. Formally, MF mechanisms can be viewed as optimization tasks where regularization terms can be added to enforce on the involved factors certain constraints capable of highlighting useful properties in data. In this context, the tuning of the HPs controlling the weight of the additional constraints is a problematic issue. In this work, we consider the choice of HPs from the point of view of optimization, incorporating them directly as a part of the updating process in a bilevel formulation. We consider the HP tuning problem in the regularized MFs context, focusing on the nonnegative factors. We review this problem and discuss its main challenges providing a new approach to its solution.

■ TD-56

Tuesday, 14:30-16:00 - Virtual Room 56

OR models and solutions to sustainability problems

Stream: Combinatorial Optimization
Invited session
Chair: *Lorena Pradenas*

1 - An integer model to select and schedule research projects in multiple Antarctic stations
Mauricio Vega-Hidalgo, Lorena Pradenas, Víctor Parada

In situ science, carried out in Antarctica, is relevant to understand many phenomenons that occur on Earth. Climate change is one but there are other examples where the Antarctic conditions make it ideal for studies. However, there are notorious drawbacks to execute these types of research: Access is difficult; resources are scarce and distributed in different stations; some areas are restricted to specific research, or even the scarce resources might not be always available. Also, some research requires specific areas and time windows. Furthermore, there is a subset of projects included in the Schedule. We can thus formulate a problem as follows: Consider a set of applied research projects to be conducted, a set of resources, a set of stations, and a time horizon. Each project has resource requirements, duration, and profits related to timely completion. We can transport some resources between stations, but in certain stations, we cannot use certain resources. Therefore, we consider a transportation time when we need the same resource in different stations. The objective is to select and schedule projects in multiple stations such that they maximize the total profit. In this work, we propose an integer model that represents this problem. We generate random test instances that simulate real-life situations and solve them with CPLEX. For small instances, we can obtain optimal solutions, but for bigger instances, we can only obtain feasible solutions after 3600s of execution.

2 - A Piecewise-Linear Approximation approach for the Pollution Routing Problem
Roberto Zanotti, Daniele Manerba, Renata Mansini, Sandra Ulrich Ngueveu

The Pollution Routing Problem (PRP) is a well-known variant of the classical Vehicle Routing Problem that aims at finding routes for a homogeneous fleet of vehicles to meet the customers' demand while respecting vehicle capacity constraints and service time windows. The objective is to minimize the overall total cost consisting of emissions, operational, and drivers' costs. Despite the intrinsic non-linearity of the problem, all the approaches available in the literature [1] are based on the discretization of the vehicles' speed, which allows to model the problem through Mixed-Integer Linear Programming (MILP). Instead, we exploit some recent results [3] to provide a non-necessarily continuous piecewise-linear approximation of the non-linear PRP objective function. The method generates, given the desired error tolerance, upper and lower bounding functions minimizing the number of required pieces. This way, new piecewise function-based MILP formulations can be derived for the PRP. The solution of the new formulations is obtained by exploiting classical VRP as well as tailored cuts. The approach is tested on benchmark instances, showing promising results.

References [1] Tolga Bektaş and Gilbert Laporte. The pollution-routing problem. Tr Res B: Meth. 45(8):1232-1250,2011 [2] Sandra Ulrich Ngueveu. Piecewise linear bounding of univariate nonlinear functions and resulting mixed-integer linear programming-based solution methods. Eur J Op Res 275(3):1058-1071,2019

3 - Transport of Skips between Recycling Centers and Treatment Facilities
Sanne Wøhlk, Gilbert Laporte

The problem studied in this paper originates from a corporate research agreement with a number of waste companies in Denmark, but is also relevant in many other contexts. It is the problem of picking up full skips from a number of recycling centers, and depending on their content, transporting them to specified treatment facilities where they are emptied. Finally, the empty skips are returned either to their origin or to another place where they are requested. We study two versions of the problem. In the first version, each skip must be returned to its origin. In the second version, the return of skips is flexible, but at the end of the working day, each recycling center must have received as many skips of each type as they started the day with. The skip types are determined by size and other factors. The study is based on 80 real-life instances from four areas in Denmark. The instances contain between five and 185 requests, with the number of skip types varying between two and seven. Based on these instances, we investigate the benefits of allowing flexible return. To solve the problem, we propose a variable neighborhood search-inspired heuristic. Due to the triple of activities and the presence of time duration constraints, this pickup and delivery problem is relatively tight. We therefore allow routes to temporarily exceed the time duration constraint, and we always insert requests at the end of the routes in the shake, and rearrange the routes in the VND.

4 - A Branch-and-Price algorithm for the electric freight vehicle scheduling problem
Patrick Klein, Maximilian Schiffer

Electric Commercial Vehicles (ECVs) constitute a promising alternative to conventional internal combustion engine vehicles as they allow for (locally) emission-free operations and may reveal economic benefits resulting from low operational cost. However, realizing economically worthwhile ECV operation remains challenging as often sparse charging infrastructure and long recharging times limit recharging operations to the depot. Here, ahead of time scheduling is necessary to guarantee charger availability. Potential cost savings through time-varying energy prices and deaccelerated battery degradation further complicate this planning problem. This talk formalizes and solves the arising scheduling problem. For this purpose, we model the problem on a time-expanded network and develop an exact branch and price algorithm based on a set partitioning formulation. The pricing problems constitute an extension to the fixed-route vehicle charging problem, introducing time windows and energy cost. We propose a labeling algorithm to solve the resulting shortest path problem. Our approach outperforms state-of-the-art integer programming solvers on a large set of benchmark instances. We further assess the impact of specific instance parameters, e.g., fleet size, planning horizon length, on our algorithm's performance. Our study confirms the scalability of our algorithm. Finally, we show the impact of depot charge scheduling on a fleet operator's overall cost for realistic instances.

■ TD-57

Tuesday, 14:30-16:00 - Virtual Room 57

Local search and metaheuristics 2

Stream: Heuristic Optimization
Invited session
Chair: *Duc-Minh Vu*
Chair: *Thanh Tan Doan*

1 - Solving The Uncapacitated Single Allocation Green p-Hub Center Routing Problem using a Clustering Based Simulated Annealing Heuristic
El Mehdi Ibnoulouafi, Mustapha Oudani, Mounir Ghogho, Tarik Aouam

Several real problems from telecommunications, air transportation and postal deliveries are modeled as Hub-and-Spoke Networks. These networks are well-studied from the combinatorial optimization viewpoint where several problem's variants, mathematical formulations and solving methods are proposed. In this paper, we introduce the Green p-Hub Center Routing Problem (Gp-HCRP) variant considering the CO2 emissions. We formulate the problem as a Mixed Integer Program (MIP) by adding constraints that fix Time Windows for nodes concerned by the vehicle tours, as well as defining the vehicle loads. Computational results on adapted AP (Australian Post) and CAB (Civilian Aeronautics Board) Datasets using CPLEX 12.10 solver show that only small sized instances may be solved to optimality. Thus, to solve medium and large sized instances, we propose three Clustering-based Construction Heuristics to obtain initial starting solutions for a Simulated Annealing Heuristic. We conduct a comparison study between the feasible integer solutions obtained by CPLEX, within a time limit of 2 hours, and those obtained by our developed heuristic method. Results show that our algorithm outperforms the CPLEX solutions. Precisely, our approach was able to find optimal solutions or solutions with small gaps to the optimal ones on small sized instances. In addition, our best returned solutions for larger sized instances appear to outperform the best integer solutions found by the exact solver method.

2 - New models and ILS-based metaheuristic for the clustered traveling salesman problem with relaxed priority rule
Thanh Tan Doan, Nathalie Bostel, Minh Hoang Ha

The Traveling Salesman Problem (TSP) is a well-known problem in operation research with various studies and applications. We address a variant of the TSP where customers are divided into several priority groups and transportation service can flexibly change by a rule, allowing to relax each group up to d levels. The problem is called Clustered Traveling Salesman Problem with Relaxed Priority Rule (CTSP-d). In the study, we propose two new models for the CTSP-d and a metaheuristic based on Iterated Local Search (ILS) with operators designed or adapted to the problem. The experimental results show the advantage of the two new models compared to previous ones, and also the performance of the ILS providing 14 new best solutions and significantly stable results compared to the metaheuristics proposed in previous studies.

3 - A Grey Wolf Optimizer Algorithm for the Vehicle Routing Problem with Time Windows and Pick-ups and Deliveries
Milad Faramarzzadeh

A Grey Wolf Optimizer Algorithm for the Vehicle Routing Problem with Time Windows and Pick-ups and Deliveries

Milad Faramarzzadeh1, Şener Akpınar2

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The vehicle routing problem with pick-ups and deliveries and time windows (VRPPDTW) is one of the main distribution planning problems. VRPPDTW aims to find the best distribution plan that minimizes the number of vehicle used and the total travelled distance. Due to the NP-Hard nature of the VRPPDTW, practical large-scale instances cannot be solved to optimality within acceptable computational times. Therefore, it is necessary to develop approximation algorithms to tackle the VRPPDTW as effectively as possible, as we try to do within the context of this study. Accordingly, a Grey Wolf Optimizer (GWO) algorithm is designed to solve the VRPPDTW. The designed algorithm starts its search with a group of solutions constructed through the K-means algorithm. Additionally, we enhanced the algorithm by incorporating the Variable Neighborhood Search (VNS) algorithm as a local search algorithm.

Keywords: Vehicle routing problem with pick-ups and deliveries and time windows, Grey Wolf Optimizer algorithm, K-means, Variable Neighborhood Search algorithm

4 - A Practical and Large-Scale Multi-Depot Vehicle Routing Problem
Duc-Minh Vu, Emrah Demir, Vasco S. Rodrigues, Aris Syntetos, Tim Bickley

In this research, we propose a solution approach for a practical last-mile routing problem in an online grocery company. This problem is simplified and modeled as a large-scale and dynamic version of the Multi-Depot Vehicle Routing Problem with Time Windows. After studying how the current routing system of the company works and state-of-the-art routing algorithms developed for related problems, we propose a novel and customized algorithms and improvements to the existing home delivery planning tools of the company. The simulation results of the proposed algorithms with instances up to 8,000 orders show the benefit of the proposed approach in terms of a higher number of orders which can be served, a smaller average cost to serve a customer (which taking into account different cost factors including fixed charge cost for vehicles, travel costs, time windows violation costs (to ensure the quality of services), etc.), fewer vehicles, etc. The improvements can be translated into millions of additional revenue each year.

■ TD-58

Tuesday, 14:30-16:00 - Virtual Room 58

COVID-19

Stream: ORAHS: OR in Health and Healthcare
Invited session
Chair: *Roberto Aringhieri*

1 - A network Data Envelopment Analysis to estimate nations' efficiency on the fight against SARS-CoV-2
Duarte Dinis, Miguel Pereira, Diogo Ferreira, José Rui Figueira

The ongoing outbreak of SARS-CoV-2 is deeply impacting health systems worldwide. Given the current situation, it is particularly important to assess the efficiency of different health systems in responding to the pandemic. Insights can thus be obtained on the factors contributing to the best/worst performances, allowing governments and health authorities to take the necessary measures in improving their respective health systems. This paper proposes an approach based on network Data Envelopment Analysis (DEA) to assess the response of 55 countries, including the 37 OECD member countries, 6 OECD prospective members, 4 OECD key partners, and 8 other countries, which provide a reliable representation of worldwide responses. The network is modelled through a general series structure with five single-division stages - population, contagion, triage, hospitalisation, and intensive care unit -, and includes inputs related to health expenditure and specific health costs associated with the pandemic, desirable and undesirable intermediate products related to the use of masks and infected population, respectively, and desirable and undesirable outputs such as COVID-19 recoveries and deaths. From the obtained results, countries with the best mean system efficiency are all located in Europe, while the countries with the worst efficiencies are distributed across Asia, Africa, and Central and South America.

2 - A Mixed Integer Linear Programming approach for optimal policy making for controlling COVID-19
Debajyoti Biswas, Laurent Alfandari

The COVID-19 pandemic has had an unprecedented impact on global health and the economy since its inception in December, 2019 in Wuhan, China. Non-pharmaceutical interventions (NPI) like lockdowns and curfews have been deployed by affected countries for controlling the spread of infections. In this paper, we develop a mixed integer non-linear programming (MINLP) epidemic optimisation model for computing the optimal sequence of NPIs over a planning horizon, considering shortages in doctors and hospital beds, under three different lockdown scenarios. We analyse two strategies - centralised (homogeneous decisions at the national level) and decentralised (decisions differentiated across regions), for three objectives separately - minimisation of infections, deaths and cost, using actual pandemic data of France. We linearise the quadratic constraints and objective functions in the MINLP model and convert it to an MILP model. We prove analytically that the optimal sequence of NPIs always follows a strictly decreasing severity pattern. Using this property, we further simplify the MILP model into an Integer Linear Programming (ILP) model, reducing computational time up to 99 percent. Our numerical results establish that a decentralised strategy is more effective in controlling infections for a given severity budget, yielding up to 20 percent lesser infections, 15 percent lesser deaths and 60 percent lesser shortages in healthcare resources.

3 - Lockdown scheduling during pandemic
Katarzyna Gdowska, Radosław Kapłan, Roger Książek, Piotr Łebkowski

Among managerial problems faced during COVID-19 pandemic is scheduling non-pharmaceutical interventions and such actions as closing some sectors of economy or total lockdowns, which reduce the virus transmission. These actions have their negative economic and social effects. Therefore, careful scheduling is important to convince society to accept them and obey. In this paper a MIP model for lockdown scheduling in order to minimize associated social and economic costs represented here with reversed probability of survival. Results of computational experiments are presented and discussed.

4 - Real-time forecasting of COVID-19 bed occupancy in wards and Intensive Care Units
Stef Baas, Sander Dijkstra, Richard Boucherie, Aleida Braaksma

This paper presents a mathematical model that provides a real-time forecast of the number of COVID-19 patients admitted to the ward and the Intensive Care Unit (ICU) of a hospital based on the predicted inflow of patients, their Length of Stay (LoS) in both the ward and the ICU as well as transfer of patients between the ward and the ICU. The data required for this forecast is obtained directly from the hospital's data warehouse. The resulting algorithm is tested on data from the first COVID-19 peak in the Netherlands, showing that the forecast is very accurate. The forecast may be visualised in real-time in the hospital's control centre and is used in several Dutch hospitals during the second COVID-19 peak.

■ TD-59

Tuesday, 14:30-16:00 - Virtual Room 59

OR for Sustainable Development Application

Stream: OR for Development, Developing Countries and Sustainable Development
Invited session
Chair: *Sadia Samar Ali*
Chair: *Olabode Adewoye*

1 - Global post financial crisis macroeconomic determinants of capital markets' development
Daniela Serban

The link between capital markets development and economic growth has been intensively analysed and proven in the past 100 years. After broad evidence of the impact of capital markets in the economy, researchers' attention has, more recently, moved towards determining the factors influencing the development of capital markets. This paper aims to analyse the effects of key macroeconomic indicators with impact on the development of capital markets, as the stock market capitalization-to-GDP ratio, on a large database of markets around the globe, in the post financial crisis period. By applying a panel data approach on a sample of 45 markets, largest so far in this area of research, over the period of 2008-2018, we provide new evidence on the macroeconomic determinants of the capital markets' development in the post financial crisis period. One of the drivers of the research on this topic is to explore concepts or tools that could be effective in driving the development of capital markets, leading to economic development. This could be of use for Governments to integrate into the public policies and encourage the development of the private sector as well, both financial and capital markets infrastructures.

2 - Profiling Green Citizens Using Knowledge Discovery in Databases Process
Gulcan Petricli, Tulin Inkaya, Gül Gökay Emel

In this work, citizen profiles of a candidate city for the European Green Capital award are investigated. The aim is to understand whether the citizens of the subject city are psychologically and behaviorally green in the context of environmental behavior and sustainability. For this purpose, a survey research was done at the household level. An integrated Knowledge Discovery in Databases process was adopted. First, data preprocessing operations were performed. Then, a two-stage clustering procedure was implemented for clustering mixed data. In the first stage, a multi-layered Self-Organizing Map was used, and in the second stage, k-medoid and hierarchical clustering algorithms were performed. For evaluation of the clustering quality, internal validity indices were utilized. Also, PCA and permutational MANOVA were conducted for verifying the clustering results. Finally, the cluster profiles and important input variables were extracted using Classification and Regression Trees and descriptive statistics. The results reveal that (i) five distinct profiles, namely wasters, risky, economic, unconscious, and potential greens, are identified, none of which is completely green; (ii) district, family life-cycle, household size, number of rooms, altruistic and biocentric environmental concerns are the most important variables in distinguishing profiles. As a result, local policies are needed for changing the citizens' environmental perspective and consumption behavior for this city.

3 - Robust eBuses Charging Location Problem
César David Loaiza Quintana, Laura Climent, Alejandro Arbelaez

The implementation of a sustainable and efficient electric bus (eBus) transportation network requires addressing multiple concerns such as limited driving range and battery charging/discharging time. Nowadays, eBuses can travel approximately up to 200KM on a full charge and the charging time varies depending on the technology from a couple of minutes to hours. In this work, we design optimization algorithms for the robust eBus charging location problem. The charging location problem involves finding the optimal location of charging stations while satisfying certain properties of the public transportation system, e.g., satisfying the demand and ensuring that the limited driving range of the buses will not impact the service. The robust charging location problem takes into account the vulnerability of the system. A failure of a charging station might impact the daily operations of eBuses. For this reason, our algorithm incorporates a protection mechanism that allows eBuses to reach a backup charging station in case the regular one is down. We propose a MIP model to tackle this problem and with minimal disruptions in the regular operation of the eBuses. Our results suggest that the robust solution requires a small increase in the number of charging stations w.r.t., the regular charging station problem, for Irish cities (Galway and Limerick).

■ TD-60

Tuesday, 14:30-16:00 - Virtual Room 60

1D cutting and packing problems

Stream: Cutting and Packing
Invited session
Chair: *Maxence Delorme*

1 - The production and cutting processes optimization in industries with multiple plants
Kelly Cristina Poldi, Livia Pierini

Many industrial production and cutting processes have costs associated with production, setup, waste of material in the cutting process and inventory. In addition, we can consider the case of companies that have their factories located in different locations, i.e., multiple plants. This must be considered in the mathematical model for a better optimization of the process as a whole. There is an absence of studies that address the integrated lot-sizing and cutting-stock problem involving multiple plants. In this research, a mathematical formulation for the multi-plant lot-sizing problem integrated to the cutting stock problem is proposed. Computational tests have been carried out to compare the integrated problem's formulation with multiple plants and the approach disregarding interaction between plants. The computational results show the advantages of the proposed model in reducing costs. Although the transportation cost is added, the overall cost decreases.

2 - The temporal bin packing problem with fire-ups
John Martinovic, Nico Strasdat, Maximilian Selch

The temporal bin packing problem (TBPP) represents a generalization of the well-known BPP with respect to an additional time dimension, and it requires to find the minimum number of bins (servers) to accommodate a given list of items (jobs) at any instant of time. In addition, recent publications suggest to also incorporate the number of fire-ups of the respective servers as an important factor in sustainable and energy-efficient overall operation. Addressing both these objectives typically leads to challenging ILP formulations, two of which have already been described in the literature. It has been shown that the parameter used to weight the two criteria strongly influences the applicability of heuristics and, therefore, the difficulty of the overall problem, so that only favorable choices can be handled so far. Even for these tailored scenarios, the current approaches already fail to compute an exact solution of many moderately-sized instances in reasonable times. For this reason, we propose various new preprocessing techniques to strengthen the LP bound and/or to reduce the numbers of variables or constraints appearing in the existing ILP formulations as well as one alternative modeling approach for the problem under consideration. Based on numerical tests with differently characterized sets of benchmark instances, the new and improved formulations are shown to lead (on average) to better performances in terms of instances solved to optimality and computation times.

3 - Reflect, an enhanced pseudo-polynomial formulation for the bin packing and other related problems
Maxence Delorme, Manuel Iori

In this work, we study mathematical models for the famous Bin Packing Problem (BPP) in which one wants to pack a set of weighted items into the minimum number of identical capacitated bins. BPP models could be clustered into three groups: those with polynomial number of variables, those with pseudo-polynomial number of variables (polynomial in both the number of items and the bin capacity), and those with exponential number of variables. While the two former groups can be solved directly through ILP solvers, the latter needs to be embedded in a branch-and-price algorithm.

Due to the advantageous trade-off between the simplicity of their implementation and their good performances, many researchers have studied pseudo-polynomial models for the BPP in the recent years, with the common objective to reduce the number of variables/constraints they involve.

After a brief review of the pseudo-polynomial formulations that were proposed in the literature recently, we introduce reflect, a new formulation that uses just half of the bin capacity to model an instance and needs significantly fewer constraints and variables than the classical models. We show that reflect can be adapted to many related packing problems such as the variable-sized BPP, the multiple knapsack problem, and the skiving stock problem. For each problem, we carry out extensive computational experiments and we show that reflect is solved faster on average by ILP solvers than the other mathematical models

■ TD-61

Tuesday, 14:30-16:00 - Virtual Room 61

Queueing Models in Service Operations

Stream: Queues with Strategic Customers
Invited session
Chair: *Opher Baron*
Chair: *Olga Bountali*

1 - Predicting Delays in Queues with Invisible Customers
Arik Senderovich

We consider queueing settings in which we observe only a subset of the arriving customers. These situations are prominent in healthcare environments in which the data on some of the patients is missing due to technological limitations or privacy concerns. In such settings, we wish to predict the delay of an observed customer upon her arrival into the system. In the paper, we start off by presenting an exact analysis of the expected delay for an observed customer in M/M/1 queues, which illustrates the analytical difficulties of the problem in more general cases. We perform an empirical comparison between the performance of the theoretical solution and machine learning (ML) approaches that use various levels of information available. We show that ML methods that use simple temporal differences between so called observed 'events of interest' as features are competitive compared to our theoretical predictor. Subsequently, we consider the prediction problem in more general queueing settings for which there is no known theoretical result for the expected delay. In a set of controlled experiments, we show that both temporal differences between 'events of interest' and the theoretical expected delay predictor that comes from the M/M/1 queue yield accurate prediction results when fed into ML methods

2 - Capacity Management in a Pandemic Incorporating Patient Choices and Evolving Severities
Sanyukta Deshpande, Siddharth Prakash Singh, Alan Scheller-Wolf, Lavanya Marla

Motivated by Emergency Department(ED) overflow phenomena under COVID-19, we study a medical provider that operates both an ED and a clinic in a pandemic. Patients contact the provider by phone/text or present at the ED; patients can be COVID (suspected/confirmed) or non-COVID, and can belong to high, medium or low severities. Patients who contact the center may be directed to the ED (they can be seen in a few hours) or offered a clinic appointment (they can be seen in a few days). All patients - at ED or clinic - enter queues after comparing their own risk perceptions for entering a queue (e.g., wait time, contagion) versus their anticipated benefits: they enter a facility with the highest anticipated benefit. The severity of patients may also evolve while waiting to be served. The hospital system's objective is to allocate service capacity across facilities and direct patients so as to minimize costs from loss of patients due to mortality or impatience. We model the system using a fluid approximation over multiple epochs; while the feasible space for this problem can be extremely complex, it is amenable to decomposition into different regimes that can be analyzed separately. An optimal solution can be obtained by comparing optimal solutions for each of these cases. Preliminary results suggest that optimal capacity allocation involves trading off current high severity patients with preventative care of medium severity patients whose severity could later increase.

3 - Offering Differentiated Services when Customers Learn Socially
Gad Allon

Service differentiation is a standard practice adopted by a variety of businesses as a tool for maximizing revenue by catering to customers with different levels of price and quality sensitivity. In many cases, customers may learn about the service quality associated with these service grades from social channels, i.e, from other customers. However, the information available online is often incomplete. In service systems where the number of customers joining a service affects the service quality, social learning in presence of lack of information has far reaching effects.

To this end, the following questions become important— is service differentiation sustainable in a setting where customers learn socially? We model the effects of social information in service differentiation by considering a profit-maximizing firm serving two groups of customers heterogeneous with respect to price and quality sensitivity providing service in two service grades, where the customers observe service reviews from each period and use that information to decide their action for the coming period.

We exhibit that social learning is an ϵ—Best response strategy for customers in this setting. We propose that it is the presence of service choice and the resulting confusion that leads to social-learning being the best response— in a model that lacks customer service choice, private learning is the best response.

4 - Join, Balk, or Jettison? The effect of flexibility paired with the knowledge of your ranking
Olga Bountali, Apostolos Burnetas, E. Lerzan Ormeci

Customers that arrive in groups but are served individually face a convoluted manifestation of the join-balk dilemma: shall they all join, all balk, or join partially and jettison some entities? The answer depends on the level of flexibility provided to the group and the knowledge of the service discipline within the group. We consider two levels of flexibility: a dictatorial level under which a batch makes a common decision and all its entities obey (that reflects the batch interests), and a democratic level, under which each individual customer makes his own decision (that reflects the individual interests). We pair each level with two levels with respect to the discipline knowledge: the full knowledge level, where customers know their ranking within their batch, and the zero knowledge level, where they assume they will be served according to a random order. We provide a full characterization of the optimal strategies in each case considering a single server Markovian queue with generic batch size distribution. We provide insights as to why the individual and batch level interests are not aligned and explain under which circumstances entity jettison is preferable. Further, we investigate the corresponding implications on system throughput and social welfare.

■ TD-62
Tuesday, 14:30-16:00 - Virtual Room 62

Judit Lienert

Stream: Keynotes
Keynote session
Chair: *Raimo P. Hämäläinen*

1 - Addressing Environmental Decision Problems with MCDA, Problem Structuring, and Behavioral OR
Judit Lienert

Environmental decisions share characteristics that make them difficult to tackle. Usually, many stakeholders are involved, including public authorities, NGO's, local communities, or even future generations. Environmental decisions may have serious long-term consequences. Decision outcomes may be difficult to quantify and predictions highly uncertain. This talk draws on Swiss cases from river management and urban water infrastructure planning, and creating a flood alert system in West Africa. I will cover important steps of structured, participatory decision-making using Multi-Criteria Decision Analysis (MCDA; MAVT/MAUT), with a focus on behavioral aspects to integrate stakeholder preferences. Initial problem structuring is key, comprising stakeholder analysis, generating alternatives and objectives, and wise decisions on which minimal set of objectives to include. I will introduce experimental online surveys with serious games. Surveys potentially allow including a broader audience in participatory decision-making; e.g., for generating objectives, or eliciting stakeholder preferences. Uncertainty is another critical issue. Future uncertainty can be captured by combining scenario planning with MCDA. Predictive uncertainty is often addressed with probability theory, and stakeholder uncertainty about own preferences with sensitivity analyses. Recently, we proposed integrating the uncertainty of predictions and preferences using the neglected concept of expected expected utility (EEU). Moreover, timing can be decisive in environmental decisions, e.g., when choosing (wastewater infrastructure) alternatives in transition phases over time, or regarding stakeholder preferences over a series of decision workshops. Another neglected subject in practical MCDA is model building; a growing number of cases illustrate that the common additive aggregation (weighted mean) is often inadequate in capturing stakeholder preferences. I will introduce the ValueDecisions app, a new R-Shiny interface that allows addressing some of these specificities, including easy exploration of the MCDA-aggregation model. This talk invites the OR community to discover the exciting research opportunities provided by environmental decision problems, while contributing to tackling todays' serious environmental challenges.

■ TD-63
Tuesday, 14:30-16:00 - Virtual Room 63

YoungWomen4OR - Supply Chain, Logistics and Decision Support

Stream: YoungWomen4OR
Panel session
Chair: *Sibel Salman*

1 - The pickup and delivery problem with alternative locations and overlapping time windows
Alina-Gabriela Dragomir, Tom van Woensel, Karl Doerner

Sending and receiving parcels can be an inconvenience in both B2C and C2C settings. To facilitate transportation providers to expand their product portfolio with alternative concepts, we consider the pickup and delivery problem with alternative locations and overlapping time windows. The transportation requests have to be served by a fleet of homogeneous capacitated vehicles. Each request may have multiple roaming pickup locations throughout the day with non-overlapping time windows (since the product cannot be in two places at once). A request may also have multiple roaming delivery locations and additionally an alternative recipient with its own set of roaming locations. As such, multiple persons in different locations can be available simultaneously to accept a delivery. Additionally, recipients can use 24-hour locker boxes if they are located near their home. The pickup and delivery problem with alternative locations is solved with a multi-start adaptive large neighbourhood search with problem specific operators. We examine in detail different scenarios based on real data provided by an Austrian logistics provider and explore in particular the benefits of locker boxes, roaming locations, alternative recipients, and mixed customer profiles with different preferences concerning data sharing and convenience. We found that an increase in flexibility and convenience for the customers translates into cost savings up to almost 30% for the carriers.

2 - ToBLoOM - Triple Bottom Line Optimization Modelling: a modelling tool for sustainable supply chains
Bruna Mota

ToBLoOM (Triple Bottom Line Optimization Modelling) is a decision support tool for the design and planning of sustainable supply chains. It encompasses support in decisions regarding: multi-facility location and capacity allocation; inventory planning; supplier selection and allocation; purchase planning; technology selection and allocation; production planning; transportation network definition (with unimodal and intermodal options); product recovery and remanufacturing planning. These decisions are supported considering the three pillars of sustainability: economic, environmental and social, using a multi-objective approach in an uncertain environment. This tool has been applied to several case-studies in different industries, exploring different supply chain sustainability characteristics and leading to managerial recommendations towards more sustainable supply chains. In this work future plans are presented on how to further expand and improve this modelling tool based on identified current challenges and opportunities in the field.

3 - Design and Planning of Sustainable Supply Chain integrating monetization strategies
Cátia da Silva, Ana Paula Barbosa-Póvoa, Ana Carvalho

Over the years, the concern with environmental and social issues has grown as we begin to become aware of the fact that human actions could jeopardize future generations. This awareness also emerged on companies, which also started to incorporate environmental and social components in their decisions. In fact, companies and their decision-makers have an important role in the implementation of measures that promote the sustainability throughout the supply chain. However, the quantification of environmental and social impacts is not simple and the units into which these impacts are translated are not always easily understood, particularly by decision-makers. As main contribution, this research intends to: i) understand which methods allow the environmental impacts to be monetarily quantified and how they can influence the design and planning of supply chain; ii) develop an optimization tool capable of modelling decisions that can be taken along the supply chain and that translates environmental and social impacts into monetary units, easily perceived by decision-makers; iii) integrate uncertainty and financial risk assessment that includes economic and environmental performance; iv) provide managerial insights for companies to improve the impact of the performance of their supply chains. Real case-studies of companies with international supply chain are solved and based on the results insights are derived.

4 - Emergency Medical Services in Germany - Gaps between Academia and Practice

Melanie Reuter-Oppermann

In recent years, an increase in data availability and computation power led to the "rise of Artificial Intelligence (AI)". In many different domains, AI-based methods and more specifically intelligent decision support systems (DSS) are studied in research and already implemented in practice, but not yet so in emergency medical services (EMS). This is especially true for the German EMS system that falls short in terms of digitalisation in general and the use of well-grounded methods for managing and planning their logistics and processes. As the actual need for intelligent DSS in the German EMS are unclear, we have performed interviews with German EMS experts. Referring to the qualitative data, we compare the decision problems and desired DSS with existing research and identify gaps between academia and practice. The decision problem that experts referred to the most actually relates to the vehicle routing problem, a well-known and well-studied Operation Research problem. Therefore, we have asked experts about barriers preventing the implementation of state-of-the-art research findings in practice. Based on the findings we have started research projects that we will briefly outline in this talk.

Tuesday, 16:30-18:00

■ TE-02

Tuesday, 16:30-18:00 - Bulding A, Room A5

New Perspectives in Queues

Stream: Performance Evaluation of Queues
Invited session
Chair: *Antonio Castellanos*

1 - The impacts of resource sharing in multi-user warehouses

Negin Jamili, Pieter van den Berg, René de Koster

In this research, we evaluate business models for a 3PL company providing multi-user warehouses. DSV, NOSTA Group, CEVA Logistics, and Varuna group are some examples of such logistics providers operating multi-user warehouses in different locations around the world. These warehouses have a broad scope of applications; thus, it is worth researching how to organize these multi-user warehouses efficiently, while taking into account both the provider's and the clients' perspectives. The main focus is to evaluate the impact of sharing the provider's resources (labor and storage space) among clients. Sharing the labor (order pickers) and space helps to create balance in workload and enhance space utilization, respectively. However, sharing resources also has downsides such as limiting picker specialization, more coordination to manage the location of items for storing and picking, and enhancing the risk of clients' items getting mixed. Therefore, we need to investigate the trade-off and find the optimal policy for such a system. We develop queuing models to evaluate different scenarios (sharing or not sharing labor or storage space) for a multi-user warehouse. We analyze each system mathematically and determine its performance using measures capturing both the provider and client perspectives.

2 - Dependency Between Arrival Times in Queueing Systems

Petra Tomanová, Vladimír Holý, Ondřej Sokol

The times between successive arrivals in queueing systems typically exhibit strong seasonal and diurnal patterns. By analyzing a wide range of retail datasets, we show that even after proper seasonal and diurnal adjustments, times between successive arrivals are still autocorrelated. We argue that ignoring this autocorrelation structure in the modeling procedure leads to a significant underestimation of performance measures of queueing systems and consequently suboptimal decisions. To avoid such unwanted consequences, after adjusting the arrival times for diurnal and seasonal patterns by cubic splines, we capture the remaining autocorrelation by the autoregressive conditional duration model with the generalized gamma distribution and score dynamics. In a simulation study, we investigate the effects of the dynamic arrival model on the number of customers, the busy period, and the response time in queueing systems with single and multiple servers. Moreover, we demonstrate that the methodology is flexible enough to provide a good fit of arrival times from both online and brick-and-mortar stores with various business focus. The datasets also differ in the length of the monitored period, time precisions as well as the frequency of visits and other characteristics.

3 - The Co-Production of Service: Modeling Service Times in Contact Centers Using Hawkes Processes.

Antonio Castellanos, Andrew Daw, Galit Yom-Tov, Jamol Pender, Leor Gruendlinger

In contact centers, a successful service interaction involves a customer-agent messaging dialogue. Both parties depend on one another for information and problem solving, and this interaction defines a co-produced service process. A key observation on this work is that this process has cross- and self-exciting dynamics. The cross-excitation stems from the two parties responding to one another, and the self-excitation captures one party's follow ups to their prior message.

Hence, messages beget messages, and we capture this by introducing Hawkes process models of the conversations. Specifically, our models distinguish between the roles of the parties, reflect the dynamic evolution of a service process over time based on its history, and include behavioral and operational aspects, such as customer sentiment and concurrency. To evaluate our proposed models, we apply them to data from a large contact center. We show that they provide a better representation of the service dynamics than the classic Poisson and phase-type models. Indeed, we find that conversations are characterized by strong customer-agent dependency and the centrality of the cross- and self-excitation attributes. Finally, we use the proposed models to improve upon routing algorithms. We show how an activity-based dynamic routing, that is based on predictions easily computed from our models, outperforms current concurrency-based routing rules, demonstrating how our models can improve operational decision making.

■ TE-03

Tuesday, 16:30-18:00 - Bulding A, Room 3A

Supply chain planning - on site

Stream: Production and logistics and revenue management (contributed)
Contributed session
Chair: *Aleksandra Komorowska*

1 - Product Proliferation and Supply Chain Games
Lijue Lu, Mozart Menezes

The strategic importance of product proliferation has been highlighted in the past decades. It is commonly believed that the increase in product variety can help firms with market segmentation, thus achieving better sales performance and higher profitability. However, product proliferation also suggests greater manufacturing complexity, heavier operation costs, and higher defect rate. Firms need to weigh up all the pros and cons to carefully choose the optimal number of products.

In this paper, we study a Stackelberg game in supply chain management where the manufacture - the leader - determines the wholesale price, and the retailer - the follower - decides the retail price and the number of products that are put on sale, which have direct impact on the consumer demand. The objective is to investigate the relationship between supply chain members using game theory, and to study how that relationship and the decision-making process are affected by the increase, or decrease, in the number of products in the sales portfolio.

We characterize the Stackelberg equilibrium and evaluate the effects of product proliferation. Payoffs under different supply chain structures (centralized/decentralized) are also analysed and compared to access the efficiency. We finally discuss some managerial implications.

2 - The impact of the introduction of a capacity market on the decarbonisation of the Polish power system
Aleksandra Komorowska

The main objective of the study is to analyze the impact of the introduction of a capacity market on hard coal and lignite consumption for electricity generation in Poland up to 2040. To this end, a computable model of the Polish power system is developed. The model is formulated as a linear programming problem. The impact of the introduction of a capacity market on the decarbonization of the Polish power system is assessed based on the following indicators: (i) coal-fired generation capacity in the power system, (ii) electricity generation from coal-fired units, and (iii) coal consumption for electricity generation. The results indicate that the decarbonization of the Polish power system is inevitable by 2040 regardless of the scenario analyzed. Hard coal consumption decreases by 86.9% and 87.9% in the Energy Only Market (EOM) and Capacity Market (CM) scenarios, respectively. Lignite consumption is reduced by 91.8% and 93.0% in the EOM and CM scenario, respectively. The introduction of a capacity market results in a delay in the process of decarbonization of the Polish power system. A slowing down of the process of withdrawing hard coal-fired power generation units is observed in 2021-30, and in the case of lignite-fired units in 2031'-32. Consequently, the implementation of the capacity market ensures the stability of energy supplies during the first phase of the decarbonization process of the Polish power system.

■ TE-04

Tuesday, 16:30-18:00 - Bulding A, Room 3B

Models for Disaster Preparedness and Response

Stream: Humanitarian Operations
Invited session
Chair: *Begoña Vitoriano*

1 - A heuristic approach for an evacuation and supply distribution problem facing a natural disaster.
M. Teresa Ortuno, Inmaculada Flores, Gregorio Tirado

Some media have named year 2020 as "The Worst Year Ever" and there are several reasons for it. The global COVID-19 pandemic with its associated lockdown and economic downturn, a wave of civilian protests around the world and general political instability are motivations of it. Furthermore, an increase of at least 12 percent of natural disasters with respect to the 21st century average (2000-2019) has deeply affected the population over the world. A coordinated and optimized response is required to minimise the impact of a disaster on the population. Two main ways of coping with the first consequences of disasters are evacuation and sheltering. While most people will evacuate by their own means, following authorities' instructions, some may not be able to do so and will need assistance. Besides, shelters need to be allocated with the necessary supplies to fulfil the evacuees' needs during their stay. The optimization problem dealing with the assisted evacuation of the affected population and the distribution of required supplies to the shelters is significantly complex and difficult to solve. In this work a MIP model and an algorithm based on the GRASP metaheuristic are presented and tested on a Case Study.

2 - Scenario generation from historical data for humanitarian logistics preparedness models
Begoña Vitoriano, Adán Rodriguez

The disaster management cycle is a process that involves several phases, some before a disaster occurs (Prevention / Mitigation and Preparedness) and others after (Response, Recovery and Assessment). In the preparation phase, the logistics processes for the establishment of the logistics network (strategic planning) and the resources pre-positioned to be used in disaster response (tactical planning) are developed. Uncertainty is a key factor to be considered for this planning. Mathematical models for decision support can incorporate this uncertainty through quantified and valued scenarios of potential disasters in the targeted geographic area. This presentation introduces a methodology followed to generate scenarios for a multi-stage stochastic model for the location and sizing of warehouses (strategic decisions) and the budget allocation and pre-positioning of relief aid (tactical decisions), taking into account response scenarios (decisions operational). The methodology is based on historical disaster data, generally relatively scarce and incomplete for this type of problem, especially for developing countries. This difficulty, together with the need to keep the number of scenarios limited for their subsequent inclusion in optimization models, leads to the use of different methodologies for classification and aggregation of historical cases. The application of the methodology is illustrated in the case of Mozambique.

■ TE-05

Tuesday, 16:30-18:00 - Building Δ, Room Δ105

Further topics in Energy Management (onsite)

Stream: Emerging technical and financial aspects of energy problems
Invited session
Chair: *Anthony Papavasiliou*

1 - Integrating feasible balancing of the network system with the p2p energy trade mechanisms for flexible peers
Mariusz Drabecki, Eugeniusz Toczylowski

With recent surge in penetration of power systems by distributed energy sources, the peer-to-peer distributed energy trading scheme have gained more interests. It allows individual peers to bilaterally trade energy in order to satisfy requirements and balance the system. Various types of peers can be considered, such as active prosumers, community sources, storages or others. In this paper we consider also a general type of peers, the Flexible Community Prosumer with Storage (FLECSP), that may include Electric Vehicles (EV).

In this paper we investigate the concept of integrating the p2p energy trade mechanism with feasible balancing of a power system. To provide security and feasibility of the energy flows over the network, an auxiliary optimisation proble with control of operation of the peers is also given, considering all grid's reliability constraints. The problem is to calculate optimal controls for day-ahead with 15 minutes granularity. FLECSP is assumed to take the portfolio optimisation decisions, to maximise its profit, by planning the best composite profiles over the horizon, withing multicommodity balancing market model. All taking into account all its resource and reliability constraints. To improve the distributed balancing between peers, the role of brokers and intermediary agents is also analysed.

Performance of the approach is assessed in simulations both from the individual peer's and the whole grid system economic and technical perspectives.

2 - Innovation decisions for green products: the role of regulation incentives and acquisitions in a duopoly game
Inês C Nunes, Margarida Catalão-Lopes

The need to address climate change is a major global concern and exploring and implementing a new model for a low-carbon sustainable economy is inescapable. Technological innovation arises as an essential element of green growth, especially since meeting long-term environmental targets requires substantial technology adoption. This paper analyses low-carbon investment and innovation decisions by firms in a vertically differentiated duopoly. We consider that firms may receive incentives from the government, in the form of subsidies or taxes, and that one of the firms may opt for an acquisition to obtain the desired low-carbon innovation. Consumers may also receive incentives from the government. Due to the multi-agent nature of the problem, game theory is used to assess the above-mentioned interactions. Results provide population thresholds for both consumers and firms regarding the switching decision between green and non-green behavior and suggest that, ultimately, firms control the extent to which consumers convert to green. To our knowledge, the role that acquisitions may have on this green technology transfer and innovation, and further consequences on competition and welfare, represent a gap in the literature. These questions are important not only from a theoretical perspective but have also significant implications for policymakers and managers, since low-carbon sustainable development, and related challenges, occupy increasing amounts of managerial resources.

3 - A matheuristic for solving non-convex economic dispatches
Loïc Van Hoorebeeck, P.-a. Absil, Anthony Papavasiliou

This talk is focused on solving non-convex economic dispatches, which is an important task in power systems consisting in the optimal allocation of the committed generating units to meet the system load at lowest cost.

Consideration of the valve-point effect, a physical effect occurring in large gas power plants, and quadratic power losses makes this problem a challenging non-smooth and non-convex optimization problem.

We developed a two-stage matheuristic which obtain a competitive objective along with a lower bound. The first step computes the lower bound and a first solution by solving a relaxed version of the problem, where the objective is linearly under-approximated and the feasible set relaxed. The second step improves the solution previously obtained with a local Riemannian subgradient scheme.

The method is bench-marked on standard test cases, and the lower bound allows us to know how close our solution, and others from the literature, are to the global solution.

■ TE-06

Tuesday, 16:30-18:00 - Building Δ, Room Δ103

Topics in Combinatorial Optimization II

Stream: Combinatorial Optimization
Invited session
Chair: *Silvano Martello*
Chair: *Paolo Toth*

1 - Matheuristic Algorithms for the Quadratic Multiple Knapsack Problem
Paolo Toth, Laura Galli, Silvano Martello, Carlos Rey

In the Quadratic Multiple Knapsack Problem (QMKP), we are given m knapsacks and n items: each knapsack has a capacity, and each item has a weight and a profit, each pair of distinct items produces an additional profit if both items are assigned to the same knapsack. The objective is to select m disjoint subsets of items to be assigned to the m knapsacks so that the total weight of each knapsack does not exceed its capacity and the total profit (sum of the profits of the selected items and of the pairwise profits of the items assigned to the same knapsack) is maximized. QMKP is a generalization of both the (Single) Quadratic Knapsack Problem and the Multiple Knapsack Problem. It is strongly NP-hard and very difficult to solve in practice. We propose effective matheuristic algorithms, based on the Lagrangian Relaxation of the QMKP models and on the optimal solution of Integer Linear Programming models. Computational results on small-size benchmark instances and on new randomly generated medium-size instances (with up to 60 items) are reported. These results show the good performance of the proposed matheuristic algorithms, which are able to determine, within reasonable computing times, solution values very close to those of tight upper bounds.

■ TE-07

Tuesday, 16:30-18:00 - Building Δ, Room Δ102

Modeling Decisions with AI

Stream: AI and Decision Making
Invited session
Chair: *Nikolaos Doukas*
Chair: *Angelos Mitretodis*

1 - Progressive hedging for adequacy aware generation expansion planning
Sebastian Gonzato

Generation expansion planning models (GEPMs) are frequently used to inform energy transition studies on possible decarbonisation pathways. There is a trend in the literature to increase the temporal scope of GEPs in order to address the challenges associated with modeling storage, renewables and adequacy, but this increases computational complexity. This study investigates the suitability of progressive hedging (PH) decomposition to solve such problems, with particular focus on the validity of PH for MILPs and how cross-scenario constraints can be included. A case study will illustrate how a loss of load expectation (LOLE) target can be included in this framework and how such differs from an expected energy not served (EENS) target.

2 - An Actor-Critic algorithm with GNN to solve the train dispatching problem
Valerio Agasucci, Giorgio Grani, Leonardo Lamorgese

In railway systems, delays occur daily, leading to a mismatch between scheduled arrival time and actual arrival time. When the delay of one train is propagated to others, a loss in service quality arises, increasing costs and decreasing the quality of the service. Dispatchers monitor the traffic minute by minute, taking re-scheduling and re-routing decisions in near real-time. This is the train dispatching problem. Many exact algorithms are presented in the literature, but the computational effort often exceeds the time window available to solve them. In this talk, we propose a Deep Reinforcement Learning framework able to solve the problem in a time compatible with the application, while handling railway rules which could otherwise be hard to model. The approach belongs to the family of Actor-Critic methods, characterized by two operators: the Actor, which gives a measurement (in terms of the probability distribution) on how good an action is, and the Critic, which estimates the value associated with each state. For both Actor and Critic, we choose to exploit the graph structure of the railway network by adopting Graph Convolutional Neural Networks as estimate models. Results show that the algorithm performs better than other learning-based approaches, like matrix-based Q-learning and Deep Q-learning.

3 - A Multi-Agent Deep Reinforcement Learning engine for a real-time policy assessment in complex NEXUS environments
Nuria Nievas Viñals, Lluís Echeverria Rovira, Adela Pages Bernaus, Xavier Domingo

The water-energy-food-land-climate (WEFCL) nexus approach is a novel methodology useful to model the complex interlinkages between the different WEFCL elements and assess at different spatial and temporal scales the impacts of the implementation of policies in the nexus. In complex systems, such as country-level nexus environments, which considers both national and regional WEFCL interconnections, a global climate and cost efficient policy assessment may result in a challenging task due to the complexity and dimensionality of these dynamic environments, where the implementation of several policies, in different regions, can hinder progress towards general objectives. In this work, a real-time assessment approach to address this combinatorial policy problem is presented. Deep Reinforcement Learning (DRL) is an Artificial Intelligence research field that combines Reinforcement Learning and Deep Learning and has been applied to solve numerous complex decision-making problems in several domains. Furthermore, DRL has recently made significant progress in multi-agent systems. The aim of Multi-Agent Deep Reinforcement Learning (MADRL) is to solve complex tasks integrating multiple agents. This study proposes a real-time policy assessment MADRL engine focused to maximize overall national nexus performance indicators by providing smart agents for regional policymaking in a WEFLC nexus environment. The results obtained are compared with heuristic methodologies.

4 - Indicating potential crises without prior knowledge
Angelos Mitretodis, Nikolaos Doukas

Throughout times of crises all stakeholders such as governments, the media, security services, aid agencies, etc., seek to acquire situation awareness as quickly as possible. Achieving this goal involves a continuous process of gathering information from a combination of different sources. Perception, understanding and the ability to predict the course of events in the near future is needed. The plethora of information networks that operate today, such as sensor networks, surveillance networks, social networks, internet, etc., can contribute significantly to the acquisition of the required awareness. The volume and complexity of these sources make it difficult or impossible for them to be used directly by those concerned.

This study uses computer techniques to process text that is freely available on World Wide Web, with the aim of obtaining advanced indicators of potential crises. These techniques include natural language processing, data mining, machine learning, emotion analysis as well as human-user interface and appropriate visualization methods. Additionally, algorithms are presented, which can in a certain time cope with the presented volume of data. Techniques for collecting, storing, searching, merging different data sources are also presented. For the study publicly available Social Media data were used. The techniques presented are intended to be used in the design of Decision Support Systems (DSS) aimed at crisis detection.

■ TE-08

Tuesday, 16:30-18:00 - Building Δ, Room Δ101

Retail Operations and Food Production

Stream: Demand and Supply in Consumer Goods and Retail
Invited session
Chair: *Navid Mohamadi*

1 - Assessing CO2, NoX and noise emission reduction potential of last mile interventions using a large-scale urban simulation model
Lena Bell, Stefan Spinler, Matthias Winkenbach

Rising levels of CO2, NoX and noise emissions in the urban environment stemming from last mile delivery vehicles have been a prominent concern for many years. With COVID-19 further amplifying ecommerce, the urge to establish sustainable last mile delivery systems to preserve quality of life becomes even more explicit. As a consequence, innovative delivery concepts like parcel shops, parcel lockers and fleet electrification have been suggested.

This paper establishes a robust simulation-based environment to assess and compare different combinations and levels of the three interventions. The aim is to find the optimal constellation of interventions to best reduce CO2, NoX and noise emissions while considering delivery costs, delivery time and investment needs. We combine macroscopic traffic simulation, continuum approximation, scenario-planning and design of experiment practices. Using a case study, real-world datasets and actual route data from a leading online retailer, we demonstrate the effects of the last mile interventions in Berlin in 2023.

The results show that the optimal constellation of the investigated last mile interventions leads to significantly lower CO2, NoX and noise emissions at stable delivery costs, delivery times and investment needs. By creating an abatement-investment-curve, we highlight a trade-off between ecological and economic benefits and show that the entire last mile ecosystem needs to take action to foster urban quality of life.

2 - Supply chain coordination for perishable products under "minimum life on receipt" (MLOR) agreements
Navid Mohamadi, Sandra Transchel, Jan C. Fransoo

We consider a supply chain of one retailer and one supplier working with limited shelf life products, specifically groceries. The retailer only accepts products with a remaining shelf life no shorter than a threshold known as minimum life on receipt (MLOR). The supplier faces a positive production lead time: the production decision is made before the retailer's order is realized. First, we design coordination contracts where the retailer is a Stackelberg leader and offers a contract to the supplier, who only accepts it if his expected profit exceeds his reservation profit. We show that coordination is possible when the supply chain is either retailer or supplier operated. In the supplier-operated supply chain, coordination is achievable only via a two-part tariff contract with a zero wholesale price and a fixed side payment. In a retailer-operated supply chain, coordinating contracts are limited to a two part-tariff contract with a wholesale price equal to the production cost and a fixed side payment to guarantee the supplier's reservation profit. Second, we employ an analytical study and a numerical example to analyze the MLOR agreements' effect on supply chain profit and waste. We analytically prove when the retailer does not require the freshest products, the supplier can accept lower wholesale prices. We show that by simultaneously reducing the wholesale price and the MLOR level, the entire supply chain's profit increases, while the waste decreases significantly.

■ TE-21

Tuesday, 16:30-18:00 - Virtual Room 21

Understanding the practice of Problem Structuring Methods

Stream: Soft OR and Problem Structuring Methods
Invited session
Chair: *Mike Yearworth*

1 - Negotiating Problem Structuring Processes to Address Water Challenges in India.
Tara Saharan, Lisa Scholten

India is facing many water-related challenges that threaten fragile ecosystems, public health and livelihoods. Despite much attention over the past decades, huge water challenges remain. Addressing wicked problems that transcend geographical and institutional boundaries with multiple problem owners present several challenges for the participants as well as the facilitators. In the course of an Indo-European research and innovation project, we designed and conducted problem structuring for wastewater management in Delhi and Kanpur. This study explores how process negotiations based on internal project dynamics, positionality, gatekeeping and external constraints influence problem structuring for wastewater governance? Problem structuring is conducted with stakeholders identified via a scoping workshop, prior engagements and stakeholder analysis done with project partners. Data collection included interviews, survey and workshops, all done online, next to process mapping of key events. The research suggests that political, institutional and social context of the actors and absence of a singular problem owner influences what is considered an acceptable process and participation; and therefore the common vision of problems. Findings of this research suggests that positionality of the facilitators and gatekeeping has direct bearing on access in problem structuring. Recommendations for better consideration of these aspects for process design are stressed.

2 - A framework to design and implement a multi-methodological systemic intervention
Alberto Paucar-Caceres, Maria Alejandra Castellini

Multi-methodology in Operational Research (OR) practice has become increasingly popular amongst OR practitioners. Based on Mingers's framework for mapping OR methodologies/methods/techniques and the three notional systems (Problem Content System, Intellectual Resources System, and the Intervention System), this presentation advances a systemic framework to enhance the design and implementation of a real-world systemic intervention. The framework was tested in a textile SME in Norwest Argentina. During four years, the project team engaged with stakeholders of the organisation to analyse the SME problematic situation, design proposals and facilitate actions through organizational management processes. Using Mingers' multi-methodology map, a range of soft/hard OR methodologies, operation management tools and workshops were organised and tried during the intervention. Results/recommendations of the intervention were adopted by the SME to improve its operations and processes suggesting that reflection helps the design and viability/sustainability of a multi-methodological intervention results. The presentation contributes to the debate about the burgeoning multi-methodological practice of mixing methods in OR practice by proposing a novel framework and by reporting results of a real-world application.

3 - Designing a research programme for OR
Jan Frelin

In 2019 FOI were tasked with designing a research program for military OR, which was to cover the future needs of OR support to Swedish military. We applied multi-methodology including factor analysis, SWOT, interviews, SCA and MA. This presentation will focus on the methods, but will also touch on our recommendations.

4 - Reading and Discussing Fiction to Enhance Creativity and Systemic Thinking of OR Practitioners
Leila Abuabara, Alberto Paucar-Caceres, Daniela Simonini Villas Boas, Mischel Carmen N. Belderrain

Operational Research (OR) graduate programs are designed based on a set of mainly technical-scientific oriented units. A small proportion of programs include soft OR units to provide graduates with skills to understand and explore human perceptions, and personal perspectives of people's involvement in a complex situation. Despite these isolated efforts, the emphasis lies still on the provision of hard oriented units than that of units that can help the understanding of human nature. We content that reading and discussion literature fiction can both enhance creativity and equip OR practitioners to become more open to others' perspectives. This article proposes an exercise to provide of a more humanistic vision when tackling real-world problems. We use a fiction reading three-stages methodology called Reading Labs, where a group discusses a fictional story. Reading Labs encourages them to declare their different point of views about the story; the methodology allows participants to become more sensitive and tolerant to others' perspectives. We report on the case of a group of people from different backgrounds reading 'The picture of Dorian Gray' story. Cognitive mapping was used to translate subjectivity of this shared literary experience and structure a discussion to share perspectives. Findings suggest that Reading Labs can help to enrich OR practice and enhance the humanistic, systemic view, education and learning of OR practitioners.

■ TE-22

Tuesday, 16:30-18:00 - Virtual Room 22

Theory and methods for continuous bilevel optimization II

Stream: Bilevel Optimization
Invited session
Chair: *Patrick Mehlitz*
Chair: *Alain Zemkoho*

1 - A New Approach for Solving Linear Bilevel Programs Based on Parameter-Free Disjunctive Decomposition
Saeed Mohammadi, Mohammad Reza Hesamzadeh, Steven Gabriel, Dina Khastieva

Several engineering problems are modeled as linear bilevel programs (linear BLPs) where one problem (upper-level problem) has constrained variables which are optimal solutions of another problem (lower-level problem). The well-known single-level reformulation approach replaces the lower-level linear program with its Karush-Kuhn-Tucker optimality conditions and then linearizes the complementary slackness conditions employing the big-M technique. Although this approach is relatively simple and upstanding, it requires finding the disjunctive parameters (big-M). Regularly heuristic techniques are used to tune the big-M parameters. It is well-known that these techniques could fail, even though they are common. Finding the correct big-M parameters is computational challenging and it is recently shown to be NP-hard in several applications. This research presents a new parameter-free disjunctive decomposition algorithm tailored for the linear BLPs which (1) does not need finding the big-M parameters, (2) guarantees that the obtained solution is optimal to the given linear BLP, and (3) it is computationally advantageous. Our experience shows promising performance of the proposed algorithm in solving several linear BLPs.

2 - A Robust Approach for Modeling Limited Observability in Bilevel Optimization
Yasmine Beck, Martin Schmidt

Many applications of bilevel optimization contain a leader facing a follower whose reaction deviates from the one expected by the leader due to some kind of bounded rationality. We consider one specific instance of bounded rationality, namely follower's response uncertainty due to limited observability regarding the leader's decision. This means that the follower does not know the exact decision of the leader but only knows that the decision lies in some uncertainty set around the exact decision. We consider bilinear bilevel problems and exploit robust optimization to model the decision making of the follower who faces the above mentioned uncertainty. The robust counterpart of the lower level is shown to be a bilinear bilevel problem as well so that a single-level reformulation can be obtained by replacing the lower-level problem with its Karush-Kuhn-Tucker conditions. An illustrative example is presented to emphasize the importance of this modeling aspect. Further, we establish an ex-post relation to bilevel problems with uncertain right-hand side data in the lower level.

3 - A Lagrange multiplier expression method for bilevel polynomial optimization
Suhan Zhong

Bilevel optimization problem is a two-level optimization problem, where a subset of its variables is constrained in the optimizer set of another optimization problem parameterized by the remaining variables. In this talk, we introduce a Lagrange multiplier expression method for bilevel polynomial optimization based on polynomial optimization relaxations. Each relaxation is obtained from the Kurash-Kuhn-Tucker (KKT) conditions for the lower level optimization and the exchange technique for semi-infinite programming. The global convergence of the method is proved under some general assumptions. And some numerical examples will be given to show the efficiency of the method.

■ TE-23

Tuesday, 16:30-18:00 - Virtual Room 23

Applications of Optimization in Engineering I

Stream: Engineering Optimization
Invited session
Chair: *Ken Harrison*

1 - Stochastic mathematical programming for integrated optimization of sublevel open stoping design and production scheduling in underground mines
Matheus Furtado e Faria, Roussos Dimitrakopoulos

Sublevel open stoping is a classic underground mining method, currently planned through a sequential optimization of the stope layout followed by mine production scheduling. The stope layout problem defines profitable extraction material volumes, the stopes, in a mineral deposit, subject to geotechnical and operational constraints. Subsequently, based on a designed development network of shafts, drifts, and crosscuts connecting the generated stopes, the sequencing of production and development activities is optimized. This process is mostly performed deterministically, ignoring the inherent deposit's spatial uncertainty and variability in metal content. In addition, the synergies between the involved planning steps are not capitalized, having adverse effects on a mining project's planning and profitability. A two-stage stochastic integer program for integrated optimization of stope design and mine production schedule is proposed accounting for grade uncertainty, quantified by a set of geostatistical/stochastic simulations of a deposit. The model seeks to maximize the life-of-mine net present value, minimize the shaft's and drifts' development costs and manage the risk of not meeting production targets to provide an optimal and operationally feasible production schedule. The application of the method at an underground gold mine generates different and more profitable schedules than a stepwise stochastic optimization of the stope design and production schedule problems

2 - Learn to Perturb: A Deep Reinforcement Learning Approach to Adaptive Simulated Annealing for Optimizing Industrial Mining Complexes
Yassine Yaakoubi, Roussos Dimitrakopoulos

Hyper-heuristics have emerged as a way to raise the level of generality of local search, unlike many approaches that may perform better but for which it's up to the user to tailor them to a given instance. This is of unique interest when solving large-scale stochastic combinatorial optimization problems where the size and complexity of industrial-problem instances make exact methods impossible to use, thus promoting approximate methods. The production scheduling of industrial mining complexes falls under this category of problems, managing the extraction of materials from multiple mines and treating them using interconnected processing facilities. To address the need for self-managed solution approaches that are able to tackle large-scale instances without resorting to aggregation, the proposed herein self-learning hyper-heuristic is a multi-neighborhood simulated annealing algorithm used in conjunction with reinforcement learning (RL), where the selection of a perturbation (low-level heuristic) is made in self-adaptive learning. By defining a neighborhood structure, the RL agent uses all related heuristics' past performance and learns how to guide the search for better solutions. Multiple state-of-the-art agents have been implemented and incorporated into the RL framework to study the robustness of the proposed method, and results show its effectiveness on multiple real-sized mining complexes, reducing the number of iterations by 30-50% and computational time by 30-45%.

3 - 0-1 optimization problems arising on feeder identification in smart grids
Larraitz Aranburu, Aitziber Unzueta, María Araceli Garín, Juan Ignacio Modroño-Herran, Aitor Amezua

One of the problems faced by the electric power distribution system operators is to know with certainty the real location of all their assets to properly manage the grid and provide the best posible service to their customers. In this work we present a procedure for the identification of which meters are connected to which low voltage feeders or distribution lines in smart grids that is based on the mathematical formulation of the problem as an optimization model. It could easily be generalized to the phase identification problem. In particular, the model is defined with 0-1 variables (as many as meters to be identified in the different feeders) and with as many restrictions as the number of points in time that are considered from the data available. Given the large size of the problem in practice, the use of conventional optimization software becomes unfeasible. Based on this approach, and making use of the linear relaxation of the problem and analytics over the coefficients (i.e., consumption) that define the time measurement restrictions of the loads of each meter in its corresponding line, we develop an iterative procedure that allows to recover the entire solution of the initial model in an efficient way. A computational experience has been carried out on a set of anonymized real data, obtaining results that support the efficiency of the proposed procedure, that moreover can be can be applied regardless of meter type or communication technology used.

4 - NIST's Alternatives for Resilient Communities (NIST ARC) Model
Ken Harrison, Shane Crawford, Jarrod Loerzel, Zeinab Farahmandfar

Hurricanes and other natural disasters cause billions in damage and widespread displacement of survivors. The Community Resilience program in the U.S. National Institute of Standards and Technology, or NIST, has developed science-based community resilience planning tools to reduce natural hazard impacts. An interactive tool, NIST's Alternatives for Resilient Communities model, or NIST ARC, was developed to facilitate stakeholder search for community-scale mitigation and preparedness actions to improve recovery from natural hazard events. The community resilience system is characterized by the large scale of the relevant and interdependent systems (e.g., power, water, transportation, buildings, education, health, economy), and the stochastic behavior of hazards and of system component failure. Model inputs include an impact/recovery interdependency network and a lines-of-defense network, in addition to node and arc information. Providing the search capability is an integer linear stochastic program with two decision stages, mitigation followed by recovery. Solution of the math program results in a mix of increases in hazard resistance and backup capacity that minimizes a measure of recovery time within budget constraints. An overview of the tool and how it fits within NIST's Community Resilience and Disaster & Failure Studies (DFS) programs will be presented in addition to case study results.

■ TE-24

Tuesday, 16:30-18:00 - Virtual Room 24

Vector and Set Optimization IV

Stream: Vector and Set Optimization
Invited session
Chair: *Ernest Quintana*
Chair: *Lidia Huerga*

1 - Ekeland variational principles for vector functions and order cones with nonempty topological interior

César Gutiérrez

The talk focuses on new versions of the well-known Ekeland variational principle in the setting of a vector equilibrium problem with a solid ordering cone. The results are obtained by a nonlinear scalarization approach and they are based on a new notion of lower semicontinuity and a new triangle inequality property

2 - Explicit Multi-objective Model Predictive Control for Nonlinear Systems Under Uncertainty

Carlos Ignacio Hernández Castellanos, Sina Ober-Blöbaum, Sebastian Peitz

In this work, we consider nonlinear multi-objective optimal control problems with uncertainty on the initial conditions, and in particular their incorporation into a feedback loop via model predictive control (MPC). For such problems, not much has been reported in terms of uncertainties. We focus on the set-based robustness which allows the decision maker to analyze a given solution from the worst-case perspective. In this kind of problems, each solution in decision space maps to a set that represents the trade-offs of the worst possible scenarios. To address this problem class, we design an offline/online framework to compute an approximation of efficient control strategies. To reduce the numerical cost of the offline phase – which grows exponentially with the parameter dimension – we exploit symmetries in the control problems. Furthermore, to ensure optimality of the solutions, we include an additional online optimization step, which is considerably cheaper than the original multi-objective optimization problem. We test our framework on a car maneuvering problem where safety and speed are the objectives. The multi-objective framework allows for online adaptations of the desired objective. Our results show that the method can design driving strategies that deal better with uncertainties in the initial conditions, which translates into potentially safer and faster driving strategies.

3 - A Vectorization Scheme for Nonconvex Set Optimization Problems

Ernest Quintana, Gabriele Eichfelder, Stefan Rocktäschel

In this talk, we consider a solution approach for set optimization problems with respect to the lower set less relation. In the first part of the talk, we derive a parametric family of vector optimization problems whose solution sets approximate, in a specific sense, that of the set-valued problem with arbitrary accuracy. In the second part, we examine particular classes of set-valued mappings for which the corresponding set optimization problem is equivalent to a vector optimization problem in the previously generated family. Further applications of these results, together with numerical examples, are also discussed.

■ TE-25

Tuesday, 16:30-18:00 - Virtual Room 25

Advances in Optimization under Uncertainty

Stream: Stochastic and Robust Optimization
Invited session
Chair: *Francesca Maggioni*

1 - Dynamic Programs with Shared Resources and Signals: Dynamic Fluid Policies and Asymptotic Optimality

Jingwei Zhang, David Brown

We consider a sequential decision problem involving shared resources and signals in which a decision maker repeatedly observes some exogenous information (the signal), modeled as a finite-state Markov process, then allocates a limited amount of a shared resource across a set of projects. The framework generalizes Markovian multi-armed bandit problems and includes a number of applications. Such problems are naturally formulated as stochastic dynamic programs (DPs) but solving the DP is impractical unless the number of projects is small. In this paper, we develop a Lagrangian relaxation and a DP formulation of the corresponding fluid relaxation — a dynamic fluid relaxation — that provide upper bounds on the optimal value function as well as a feasible policy. We develop an iterative primal-dual algorithm for solving the dynamic fluid relaxation and analyze the performance of the feasible dynamic fluid policy. Our performance analysis implies, under mild conditions, that the dynamic fluid relaxation bound and feasible policy are asymptotically optimal as the number of projects grows large. We demonstrate the model and results in two applications: (i) a dynamic capital budgeting problem and (ii) a multi-location inventory management problem with limited production capacity and demands that are correlated across locations by a changing market state.

2 - The Polyhedral Structure and Complexity of Multistage Stochastic Linear Problem with General Cost Distribution

Maël Forcier, Stephane Gaubert, Vincent Leclere

By studying the intrinsic polyhedral structure of multistage stochastic linear problems (MSLP), we show that a MSLP with an arbitrary cost distribution is equivalent to a MSLP on a finite scenario tree. More precisely, we show that the expected cost-to-go function, at a given stage, is affine on each cell of a chamber complex i.e., on the common refinement of the complexes obtained by projecting the faces of a polyhedron. This chamber complex is independent of the cost distribution. Furthermore, we examine several important special cases of random cost distributions, exponential on a polyhedral cone, or uniform on a polytope, and obtain an explicit description of the supporting hyperplanes of the cost-to-go function, in terms of certain valuations attached to the cones of a normal fan. This leads to fixed-parameter tractability results, showing that MSLP can be solved in polynomial time when the number of stages together with certain characteristic dimensions are fixed.

3 - ALSO-X is Better Than CVaR: Convex Approximations for Chance Constrained Programs Revisited
Weijun Xie

This paper studies and generalizes the ALSO-X, originally proposed by Ahmed, Luedtke, SOng, and Xie (2017), for solving a chance constrained program (CCP). We first show that the ALSO-X resembles a bilevel optimization, where the upper-level problem is to find the best objective function value and enforce the feasibility of a CCP for a given decision from the lower-level problem, and the lower-level problem is to minimize the expectation of constraint violations subject to the upper bound of the objective function value provided by the upper-level problem. This interpretation motivates us to prove that when uncertain constraints are convex in the decision variables, ALSO-X always outperforms the CVaR approximation. We further show (i) sufficient conditions under which ALSO-X can recover an optimal solution to a CCP; (ii) an equivalent bilinear programming formulation of a CCP, inspiring us to enhance ALSO-X with a convergent alternating minimization method (ALSO-X+); (iii) extensions of ALSO-X and ALSO-X+ to solve distributionally robust chance constrained programs (DR-CCPs) under Wasserstein ambiguity set. Our numerical study demonstrates the effectiveness of the proposed methods.

4 - Sample Average Approximation for Stochastic Nonconvex Mixed Integer Nonlinear Programming via Outer Approximation
Can Li, Ignacio Grossmann, David Bernal, Kevin Furman

We propose a sample average approximation-based outer-approximation algorithm (SAAOA) that can address nonconvex two-stage stochastic programs (SP) with any continuous or discrete probability distributions. Previous work has considered this approach for convex two-stage SP. The SAAOA algorithm does internal sampling within a nonconvex outer-approximation algorithm where we iterate between a mixed-integer linear programming (MILP) master problem and a nonconvex nonlinear programming (NLP) subproblem. We prove that the optimal solutions and optimal value obtained by the SAAOA algorithm converge to the optimal solutions and the optimal value of the true SP problem as the sample size goes to infinity. The convergence rate is also given to estimate the sample size. Since the theoretical sample size estimate is too conservative in practice, we propose an SAAOA algorithm with confidence intervals for the upper bound and the lower bound at each iteration of the SAAOA algorithm. Two policies are proposed to update the sample sizes dynamically within the SAAOA algorithm with confidence intervals. The proposed algorithm works well for the special case of pure binary first stage variables and continuous stage two variables since in this case the nonconvex NLPs can be solved for each scenario independently. The proposed algorithm is tested with a stochastic pooling problem and is shown to outperform the external sampling approach where large scale MINLPs need to be solved.

■ TE-26

Tuesday, 16:30-18:00 - Virtual Room 26

Interior point algorithms in convex optimization I

Stream: Nonlinear Optimization
Invited session
Chair: *Marianna Eisenberg-Nagy*
Chair: *Petra Renáta Rigó*

1 - A family of long-step interior point algorithms using transformed search directions for linear programming
Marianna Eisenberg-Nagy, Anita Varga

We characterize a new family of long-step interior point algorithms for linear programming problems. We consider the large-update interior point algorithm by Ai and Zhang (2005). This is the first long-step interior point method having exactly the same complexity as the best short-step algorithms. We use a similar wide neighbourhood of the central path and we compute the searching directions in the same split-way. We combine these ideas with the algebraic equivalent transformation technique by Darvay (2003), that is, we compute the new points along a transformed searching direction. This transformation is determined by a strictly increasing, continuously differentiable function. Our aim was to determine a family of these functions for which the best-known results of the large-update algorithm can be proven. We also present preliminary computational results comparing some already known members of this family of interior point algorithms.

2 - A new long-step interior point algorithm for sufficient linear complementarity problems with transformed search directions
Anita Varga, Marianna Eisenberg-Nagy

Based on the step-size, interior point algorithms can be divided into two main groups, short-step, and long-step methods. In practice, long-step variants converge faster; however, in most cases, a better theoretical complexity can be achieved for short-step methods. One of the exceptions is the large-update algorithm of Ai and Zhang.

In this talk, we introduce a new long-step interior-point algorithm for sufficient linear complementarity problems. The applied new wide neighbourhood and the main characteristics of the algorithm are based on Ai and Zhang's approach. The new search directions are determined using the algebraic equivalent transformation technique of Zsolt Darvay.

We show that the new method has the best-known iteration bound obtained so far by any interior point algorithm for solving sufficient linear complementarity problems. We also present our numerical results.

3 - Predictor-corrector interior-point algorithm for sufficient linear complementarity problems using a wide neighbourhood of the central path
Roland Török, Tibor Illés, Petra Renáta Rigó

We propose a new predictor-corrector interior-point algorithm for solving sufficient linear complementarity problems. In order to define the search directions we use the square root function in the technique of algebraic equivalent transformation of the central path system. We also define a new wide neighbourhood of the central path. Up to our best knowledge, this is the first predictor-corrector interior-point algorithm which works in the newly introduced wide neighbourhood. We present the complexity analysis of the method and we show the efficiency of the proposed algorithm by providing numerical results. We compare our predictor-corrector interior-point algorithm to other ones that use different search directions or different types of neighbourhoods and we obtain promising results.

4 - New interior-point algorithm for symmetric cone horizontal linear complementarity problems
Zsolt Darvay, Petra Renáta Rigó

We introduce a new predictor-corrector interior-point algorithm for solving sufficient horizontal linear complementarity problems defined on a Cartesian product of symmetric cones. We use the difference of the identity map and square root function in the algebraic equivalent transformation technique in order to determine the new search directions. We prove that the predictor-corrector interior-point algorithm has the same complexity bound as the best-known interior-point algorithms for solving these types of problems. A novelty of the result is that we provide a condition related to the proximity and update parameters for which the introduced predictor-corrector algorithm is well defined. In this way we present the first result related to interior-point algorithms using the above-mentioned search direction which is well defined for a set of parameters instead of a given value for the proximity and update parameters.

■ TE-27

Tuesday, 16:30-18:00 - Virtual Room 27

Large scale optimization I

Stream: Big Data and Optimization
Invited session
Chair: *Natasa Krejic*

1 - Gauss-Newton approach for large-scale Riccati equations
Marcos Raydan

We describe a nonlinear least-squares approach for solving large-scale continuous-time algebraic Riccati equations with a low-rank right hand side. We project the problem onto a sequence of nested Krylov-type low- dimensional subspaces. Then, instead of forcing the orthogonality condi- tions related to the Galerkin strategy, we minimize the residual at each subspace to get a low dimensional nonlinear matrix least-squares problem that will be solved to obtain an approximate factorized solution of the initial Riccati equation. To solve the low-order minimization problems, we propose a globalized Gauss-Newton matrix approach that exhibits a smooth convergence behavior, and that guarantees global convergence to stationary points. This procedure involves the solution of a symmetric matrix problem per iteration that will be solved by preconditioned itera- tive matrix methods. To illustrate the behavior of the combined scheme, we present numerical results on some test problems.

2 - Stochastic trust-region methods with inexact restoration
Stefania Bellavia, Natasa Krejic, Benedetta Morini, Simone Rebegoldi

This talk deals with trust-region methods with inexact models for finite-sum minimization problems. At each iteration, the function is subsampled through a deterministic rule inspired by the inexact restoration method, which allows for the local decreasing of the sample size. The gradient is also built via subsampling, with the gradient sample being possibly smaller than the one used in the function estimate. The trust-region step is then accepted or rejected according to the sufficient decrease of a suitable merit function, which combines the function estimate with a measure of the evaluation precision. We show that the proposed method eventually reaches full precision in evaluating the objective function and we provide an almost sure global convergence result to a stationary point. We validate the proposed algorithm on a set of convex and nonconvex classification problems, showing a good performance in terms of accuracy and stability with respect to the choice of the parameters.

3 - Learning exact solutions for geometric set cover and related problems
Dena Tayebi, Deepak Ajwani, Saurabh Ray

We study the following closely related problems: set-cover, max-coverage, facility-location, and k-median and explore if machine learning techniques can be used to obtain scalable solutions to these NP-hard problems. For the facility location and k-median problems, the existing LP-rounding based approximation algorithms are very efficient and often yield close to optimal solutions for the metric case. However, for the non-metric case, which is a strict generalization of the max-coverage problem, there are currently no efficient heuristics available. In contrast, our approach yields near optimal solutions for a wide variety of synthetic problem instances and scales well for large instances. Our main approach is to cut down the search space of solutions by using machine learning. Given an instance, we use a classifier to prune certain parts of the solution space so that an optimal solution for the remaining problem can be found efficiently. Our empirical evaluation provides evidence that (i) our machine learning based pruning reduces the running time of the subsequent Integer Linear Program significantly, (ii) the objective function value of our solution is very close to that of the optimal solution, (iii) our solution is better than that provided by the LP rounding based approximation algorithms and (iv) even on considerably large problem instances, the solutions produced by our approach can't be improved significantly using local search heuristics.

4 - An adaptive subsampled Hessian-free optimization method for statistical learning
Fabian Bastin, Jean Laprés-Chartrand, Jeremy Rieussec, Loïc Shi-Garrier

We consider nonconvex statistical learning problems and propose a variable sample-path method, where the Monte Carlo sample size is dynamically updated at every iteration to ensure a decrease in the true objective function with high probability. The variable sample scheme aims at integrating sufficient information from the true problem while minimizing the computational effort. We integrate this strategy in a subsampled Hessian-free trust-region method with truncated conjugate gradient. Outer product approximations are used to efficiently compute Hessian-vector product estimates, to evaluate the algorithm progress, and to adjust the sample size. The technique also allows efficient early stopping strategies.

The approach is compared to various adaptive sample approximation algorithms and stochastic approximation methods popular in machine learning for high-dimensional problems. The efficiency of the proposed algorithm is illustrated on various large size datasets. Numerical experiments highlight the benefits of the trust-region framework in combination with the exploitation of the information geometry.

■ TE-28

Tuesday, 16:30-18:00 - Virtual Room 28

Data Science in Marketing and Consumer Behavior

Stream: Mathematical Optimization and Data Science
Invited session
Chair: *Burcin Bozkaya*

1 - Making hard decisions: Which stores to close?
Mohsen Bahrami, Yilun Xu, Alex Pentland

Many studies have tried to propose methods for finding the best location for new stores and facilities, but few studies address the store closing problem. As a result of the recent COVID-19 pandemic many companies are facing financial issues. In this situation, one of the most common solutions to save the brand is to downsize by closing one or more stores of the chain. Such decisions are usually made based on every single store; therefore, the underperforming stores are subject to closures. In this study, we use a variation of the Huff gravity model to predict customer behavior and revenue loss after closing each chain store. We mainly study the case of department stores in New York city using SafeGraph mobility and Facteus customer spending data. The case study results suggest that the store's choice to be closed under our proposed model may not always match the single store performance, but interaction among the stores. Our proposed approach provides decision-makers with new insights into store closing decisions and is likely to reduce store closures' consequences on revenue loss.

2 - Using machine learning and satellite imagery to measure store performance
Nicole Rech, Vinicius Brei, Burcin Bozkaya, Selim Balcisoy, Mert Gurkan, Gustavo Henrique de Rosa

A traditional approach to measure store performance is to understand store traffic. This literature is anchored on understanding stores' internal traffic (i.e. customers) data, where each company measures its own sales performance based on its internal traffic. However, privacy policies and the lack of internal data often hinder companies' capacity in assessing their own or their competitors' sales performance. Considering these limitations, this paper proposes a new method to estimate sales performance, where Machine Learning (ML) algorithms are fed with remote sensing (satellite imagery) data. We move beyond recent applications of remote sensing to estimate demographic and socioeconomic activity and develop a Computer Vision algorithm to count cars in parking lots using freely available Google satellite imagery. After gathering and processing the images of 504 parking lots over Brazil, we tested different ML algorithms to estimate the relation between the number of cars at each store's parking area and the sales of a major electrical manufacturer's products. The results suggest that the relationship between sales and parked cars is nonlinear and different depending on the type of business. There was a positive and significant relationship between distributors and wholesalers, yet it was not significant when considering different types of retailers. Our approach contributes to the literature on Operations Research and sales, retail, and channel management in Marketing.

3 - Understanding utilitarian and hedonic consumer behavior in a supermarket setting

Zeynep Kucuksari, Selim Balcisoy, Burcin Bozkaya, Vinicius Brei

In the management and psychology literature, consumers' motivations to make purchases have long been studied under the dichotomic perspective of hedonic vs utilitarian decisions. This perspective is relevant to understanding why people buy and helping companies frame their strategies to optimize their sales efforts. In this paper, we analyze supermarket transaction data from Brazil to understand and identify hedonic vs utilitarian consumer behavior in a supermarket context. While current literature focuses on a general set of shopping categories, we focus on in-supermarket purchases to understand when and how consumers are inclined to make hedonic purchases. We propose measures to quantify depth and breadth of purchases along many dimensions including brand/no brand, value, quantity/amount, day and time, and location. As the definition of hedonic may change from person to person, and in the absence of ground truth, we propose an unsupervised approach to identify outlier transactions that could be considered hedonic. We also conduct a sensitivity analysis over these dimensions in outlier detection and demonstrate how they categorize certain transactions differently as hedonic. A closer examination of selected customers and their transaction sets suggests that our approach produces realistic results under a variety of dimensions and scenarios. Our approach brings new theoretical perspectives to advance the hedonic and utilitarian literature in management/operations research.

4 - Gravitational Sales Estimation

Burcin Bozkaya, Carla Netto, Mohsen Bahrami, Vinicius Brei, Selim Balcisoy, Alex Pentland

Whenever companies plan to enter a market or new geographical locations, they need to estimate sales in each location. To make such estimations, sales time-series and/or final consumers data in geographical disaggregation have always been necessary. However, such datasets are impossible for new stores, since they do not yet exist. Even if they exist, in developing countries they may be outdated or too expensive for most companies. To solve this problem, we propose a new type of agglomeration theory effect that is applied to explain area attractiveness and customer flow, and estimate sales when no actual purchase data or historical sales proportions are available. The proposed method uses a new gravitational sales estimation approach calculated based on Points of Interest (POI) effects in order to create a forecast at finer-grain levels of geographic aggregation. The resulting Gravitational Sales Estimate (GSE) is validated using sales data from industry and credit card contexts from two different companies and economic sectors from two different countries over multiple purchase categories. The proposed approach based on publicly or freely available data has a similar or better performance than the benchmark approach used to disaggregate sales that requires proprietary sales data.

■ TE-29

Tuesday, 16:30-18:00 - Virtual Room 29

Modeling Decisions with Artificial Intelligence

Stream: AI and Decision Making
Invited session
Chair: *Pascale Zaraté*

1 - Micro-grids management for isolated electric systems using linear programming

Mateo Espitia Ibarra, Pablo Andrés Maya Duque, Carolina Marín

Electricity is an essential tool for economic growth and the well-being of poor communities. This research presents an approach for electricity management into isolated systems where a group of different conventional and non-conventional generators are into an electric micro-grid. It implies the use of environmental sources such as wind, solar and hydraulic energy as the mean electric sources and consider diesel and battery system as supplementary options. Optimization strategy consists on minimize the operative cost over the micro-grid according to the amount of electricity generated by each generator through the time horizon. Simultaneously, it considers some operating constraints that ensure the complete coverage of load demand, the non-overload of the micro-grid and estimation of the electric generation levels of each one of the generators according to their technology at each period. Further, the optimization model also considers the special strategy for battery management, which tends to conserve battery life. It makes discharging process as long as possible. It keeps the battery status between healthy levels avoiding deep charge and discharge process. The model is tested with data and parameters from the Colombian context within a cloud notebook. This country has 1,798 isolated localities that are distributed in almost 51% of the national territory, which represents a real need for the implementation of autonomous systems based on non-conventional energy.

2 - Decision support for supply chain resilience in a risky environment: The DESIIR Project

Chenhui Ye, Pascale Zaraté, Daouda Kamissoko

We define the Supply Chain Risk Management (SCRM) as a process composed of four steps : Risk identification, Risk assessment, Risk mitigation, Risk control. The first step in SCRM practices concerns the identification of risks through regular screening of potential SC risks. Risk definition consists in four steps. 1.Categorize the risks: 2.Risk screening[U+FF0C] 3.Risk monitoring[U+FF0C] 4.Risk diagnosis. Risk assessment can be identified as the evaluation of risk's occurrence including an estimation of its impact. The system needs to make statistics on the impact of risks and the frequency of risks through data analysis. At this time, the risk has occurred, the system will issue an alarm, and the decision support system will intervene in the decision-making of the supply chain at this time. The decision-making suggestions made by the system are divided into four types: 1. Risk avoidance; 2. Loss control; 3. Risk transfer; 4. Risk retention. The decision support system will propose decision-making plans for supply chain managers around four core strategies, and predict the subsequent impact of various suggestions. Risk control is ensured through systematic processes, preparedness, risk awareness of employees, arti-culated procedures and elaborated plans. When the decision maker makes a decision based on DSS's recommendations, the system will track the data and various indicators of the supply chain to assess whether the impact of risk has been reduced.

3 - A Decision Support System for Improving Legal Case Handling

K.Nadia Papamichail, Mayowa Ayodele, Ian D. Miles, Darren Buckley

This paper presents a decision support tool that provides useful information to help legal professionals settle legal cases more efficiently.

The system is a data-driven adviser that extracts knowledge and generates insights from historical data about settled legal cases. A range of data science, database management and web design methods have been applied to develop a user-friendly tool that is able to provide advice to legal staff. The system operates in two modes. Firstly, it provides recommendations about settlement strategies based on a single legal case. Secondly, it provides a broader insight into all currently open legal cases for a given legal staff/team, allowing for easy comparison of strategy on different types of cases and performance metrics. This work was conducted as part of a project in a legal services firm. The results show that the system improved operational performance and the project informed the firm's ongoing data strategies.

4 - Web-based tool for algebraic modeling languages
Vaidas Jusevičius, Remigijus Paulavičius

In our research, we have conducted an extensive theoretical and experimental analysis of the characteristics of the most prominent algebraic modeling languages (AMPL, AIMMS, GAMS, JuMP, and Pyomo) and modeling systems supporting them. In a theoretical comparison, we evaluated how the reviewed modern algebraic modeling languages match the current requirements. While in the experimental analysis, we used a purpose-built test model library to perform extensive performance and pre-solving benchmarks. This provided us insights on which algebraic modeling languages performed the best and the features that we deem essential in the current mathematical optimization landscape. This also revealed gaps within the existing language and tool landscape: varying performance, limited cross-compatibility, complex syntax, and different solver and problem type support. Thus, we are proposing state of an art web-based algebraic modeling language (Web AML) and providing a prototype of the open-source tool supporting it. The tool does not require specific algebraic language knowledge, allows to solve problems using different solvers, and utilizes the best characteristics of each algebraic modeling language. We are also providing clear extension points and ideas on how such a tool could be further developed.

■ TE-30

Tuesday, 16:30-18:00 - Virtual Room 30

MILP in logistics

Stream: Mixed Integer Linear Programming
Invited session
Chair: *Daniel Rehfeldt*

1 - A Mixed-Integer Programming Formulation to Minimize Weighted Tardiness in Additive Manufacturing Environment
F. Tevhide Altekin, Yossi Bukchin

Recently, additive manufacturing (AM) and 3D printing are also used to produce high variety and low volume parts for end-users in biomedical, aerospace, automotive, and defense industries. We study the static production planning and scheduling problem for AM, where metal parts are produced using a given set of AM machines. We assume orders are received from customers who have different priorities. Each order entails a due date and the characteristics of the set of parts ordered. For each part in an order, we are given the part volume, base area, part height and desired layer thickness defining the quality grade of the part. For each machine, the build chamber's height, base area, and a set of layer thicknesses valid for the metal powder to be used are given. The remaining AM machine parameters such as the per unit volume production speed, recoating speed, and set-up time depend on the specified layer thickness. The addressed problem involves the simultaneous assignment of parts to jobs and jobs to the AM machines while also determining the layer thickness to be used. The build time to complete a job is determined both by the machine and parts specifications. A customer order is completed as soon as all parts of that order are produced. We present a mixed-integer programming formulation with the objective of minimizing weighted tardiness. The efficiency and effectiveness of the proposed formulation are demonstrated for various problem sizes taken from literature.

2 - A Column Generation approach for Container management in dry port
Sebastian Fernandez-Garrido, Pablo A. Miranda, Gabriel Gutiérrez-Jarpa

A consequence of globalization is the great number of containers that are managed daily in different strategic points of the logistic chain. One of those is the dry port where container storage service to clients (ports, retails, industries, etc.) is given during a predefined time by an agreement. The dry port must manage the containers which are stored in blocks in a yard incurring a cost by assignment to a location, relocation, and extraction until departure time. If the re-negotiation with the clients about the departure time of their containers is possible, some containers can leave the dry port at a different time than its original departure time decreasing the costs. We formulate the problem as a lineal integer model that minimizes the total cost including the departure time decision. Also, we show a first approach using column generation to solve it. Finally, a preliminary set of the instances are solved showing the efficiency of the column generation method.

3 - Robust Multistage Bin Packing via Quantified Programming
Michael Hartisch, Tobias Marx

We investigate a multistage bin packing problem in which the overall number of orders is known, but the order of incoming items is unknown. The goal is to find a robust plan for assigning items to bins such that the worst-case objective value is minimized. Originating from a real-world cutting-stock problem we minimize the number of used bins, the number of bin-changes (in order to minimize set-up time) and free space in used bins (waste of material). We use quantified programs to model this problem and compare the performance of a general solver for quantified programs with the performance of CPLEX solving the deterministic equivalent program and the performance of existing decision-rules on this robust multistage problem with integer decision variables and discrete uncertainty. Additionally, we demonstrate the benefit of utilizing a multistage framework compared to the nominal and the standard two-stage robust approach.

4 - Parallel solution of Steiner tree and related problems
Daniel Rehfeldt, Thorsten Koch, Yuji Shinano

The Steiner tree problem in graphs (SPG) is one of the most studied problems in combinatorial optimization and computer science. The current state-of-the-art solver for SPG is SCIP-Jack—being often millions of times faster than general mixed-integer programming solvers. Furthermore, SCIP-Jack can handle many related problems.

This talk discusses key components of SCIP-Jack, with a focus on the latest algorithmic developments. Furthermore, the parallelization of several algorithms used within SCIP-Jack is disscussed. Finally, we provide recent computational results, both for the sequential and parallel versions of SCIP-JACK.

■ TE-31

Tuesday, 16:30-18:00 - Virtual Room 31

Game Theory and Operations Management 3

Stream: Game Theory and Operations Management
Invited session
Chair: *Daniel Granot*
Chair: *Frieda Granot*

1 - Bike-Sharing Systems: Economic and Environmental Implications of Operational Strategies
Sanjith Gopalakrishnan, Daniel Granot, Frieda Granot

Bike sharing is fast emerging as a sustainable and environmentally friendly alternative that complements traditional modes of transportation to meet growing urban transport needs. From an operational standpoint, bike sharing presents several unique challenges. Despite the growing popularity of bike sharing, systems in several major cities, such as Seattle's Pronto and Bixi in Montreal have run into financial difficulties. High operational costs arising from system rebalancing coupled with lower than projected levels of ridership are commonly identified as major contributing factors. On the other hand, the environmental benefits of bike-sharing (as a consequence of reduced vehicular emissions from individuals substituting away from personal automobiles) might be less substantial than presumed. We consider three key strategic and operational decisions faced by bike share operators: the coverage and density of the system, the pricing model and the frequency of rebalancing. We also model the existing levels of public transport access and availability in the region. Employing a continuous approximation model, our objective is to develop a framework that can be employed by planners to design bike-sharing systems with high ridership and low operational costs which maximize environmental benefits.

2 - Characterization of TU games with stable cores by nested balancedness
Peter Sudhölter, Michel Grabisch

A balanced transferable utility game (N,v) has a stable core if its core is externally stable, that is, if each imputation that is not in the core is dominated by some core element. Given two payoff allocations x and y, we say that x outvotes y via some coalition S of a feasible set if x dominates y via S and x allocates at least v(T) to any feasible T that is not contained in S. It turns out that outvoting is transitive and the set M of maximal elements with respect to outvoting coincides with the core if and only if the game has a stable core. By applying the duality theorem of linear programming twice, it is shown that M coincides with the core if and only if a certain nested balancedness condition holds. Thus, it can be checked in finitely many steps whether a balanced game has a stable core. We say that the game has a super-stable core if each payoff vector that allocates less than v(S) to some coalition S is dominated by some core element and prove that core super-stability is equivalent to vital extendability, requiring that each vital coalition is extendable.

■ TE-32
Tuesday, 16:30-18:00 - Virtual Room 32

Trade-off between Economics and Environment: the response of cities in the shadow of COVID-19 2

Stream: Multiple Criteria Decision Analysis
Invited session
Chair: *Caterina Caprioli*

1 - Regional growth and disparities in a post-COVID Europe: a new normality scenario
Andrea Caragliu, Roberta Capello

This paper addresses the important question "Which European areas will be able to better react to the crisis induced by COVID-19 and how regional disparities will look like?". In order to provide an answer, a "new normality" scenario is built, comprising the structural changes likely to take place in the aftermath of the COVID pandemic. To develop such scenario, two intermediate steps are necessary, in both cases relying on the use of the latest generation of the MAcroeconomic, Sectoral, Social, Territorial (MASST4) Model. First, short-run costs of the COVID-induced lockdowns, in terms of missed GDP, are calculated for all European NUTS2 regions, needed because of the lack of short-run statistics about the extent of the regional costs caused by the lockdowns that will only appear in two years. Second, a long-run simulation of the economic rebound expected to take place from 2021 through 2030 is presented, assuming, among other trends, that no further national lockdowns will be undertaken in European countries. In the "new normality" scenario, regional disparity trends will decrease as a result of a decisive rebound of those countries mostly hit by the pandemic.

2 - Old towns in the "Covid-scape". The green roof response and the new city style
Maria Rosa Trovato, Salvatore Giuffrida, Cheren Cappello, Vittoria Ventura

The current environmental fluctuation, the Covid-19 pandemic, cannot be considered just as a transitory event the social system can overcome without implementing deep changes in shared motivations (values) and intentions (programmes). In the urban sustainability field, the green revolution is a great opportunity despite the occurrence, at the same time, of several market distortions, taxation inequalities and sovereign debt issues. At the different levels and detailed scales of the urban phenomenon, such an apical political-macroeconomic trade-off breaks up into several ones. Assuming the "Covid-scape" as the background of the next great deal involving the original social-environmental dialectic, the paper focuses on the green roof practice at the district scale, highlighting the trade-off between the economic opportunity of the photovoltaics development and the urban-landscape improvement. With reference to a real case study concerning a historic district, two integrated patterns were developed: at the building scale the valuation-programming pattern allows to sort each unit by the two different uses and provides the economic-environmental balance generating a wide range of strategies; at the district scale, the strategy maximising the landscape-economic balance is outlined through a decisional compensatory approach carried out by means of a flexible and interactive trade-off method developed to elicit criteria weights within the scope of the MAVT.

3 - Rethinking of territorial resilience scenarios facing Post-Covid pandemic
Sara Torabi Moghadam, Alice Borsari, Patrizia Lombardi

Cities around the world in 2019 have faced the impact and spread of the Covid-19 pandemic with unprecedented speed as a result of our hyper-connected so'ciety. As history teaches, epidemics plague society through the vulnerabilities that humans create through their relationships with the environment, with other species and with each other. The ongoing pandemic of Covid-19 is a strong reminder that urbanization has changed the way that people and communities live, work, interact, and it is necessary even more than in the past a multidisciplinary approach to develop systemic operational skills capable of dealing with complexity. The research project, called POST-UNLOCK, introduces the Local Resilience Units to promote place-based strategies. This project emphasizes the need of the definition of new territorial scenarios for the Metropolitan City of Turin considering the post-emergency phase within the framework of 2030 Agenda. The mid-term results illustrate the selection of a set of Post-Covid indicators through the consultation of already consolidated indicators within different projects and territorial databases. Based on their evaluation, and thanks to the creation of an interactive dashboard, it is possible to analyze the baseline scenario and changes that occurred during the emergency phase. These scenarios highlight the weaknesses and priority areas to act on, experimenting the "augmented city at a neighbourhood scale" as an urban response to the pandemic.

■ TE-33

Tuesday, 16:30-18:00 - Virtual Room 33

Prescriptive Analytics and Machine Learning

Stream: Business Analytics
Invited session
Chair: *Sebastian Maldonado*

1 - Causal machine learning for student dropout in higher education
Sebastian Maldonado, Diego Andres Olaya Lasso, Jonathan Vásquez, Jaime Miranda, Wouter Verbeke

Uplift modeling is a strategy for predictive Analytics that directly assesses the incremental impact of a treatment (such as a marketing campaign) on a customer's behavior. This technique has received increasing attention in customer relationship management, especially in churn prediction tasks. Instead of targeting those customers that are more likely to attrite, which is the case in traditional churn prediction, uplift modelling focuses on those customers that would churn and would be retained when targeted with a retention campaign. Uplift modelling has been successfully applied in a wide variety of domains, including political elections and personalized medicine. However, it has not been used for predicting student dropout, to the best of our knowledge. Student retention is a very relevant topic for Higher Education institutions since they are constantly facing new challenges to meet a growing set of demands as well as political, financial, and social pressures to deliver quality education to students. In this study, we propose an uplift modelling strategy for avoiding student dropout via courses designed to improve student performance, acting as retention campaigns for student dropout. Data from three different Bachelor programs from a Chilean University were collected, in which these courses are offered to all the students. Our idea is to improve the design of these courses by tailoring them to the students that are more likely to be retained with them.

2 - Analyzing customer experience via multilabel classification, deep learning, and natural language processing
Carla Vairetti, Sebastian Maldonado, Angeles Aldunate

Companies invest lots of time and money in measuring customer satisfaction, but most of the yardsticks they use are complex, yield ambiguous results, and do not necessarily correlate to profits or growth. Figuring out a way to accurately measure customer loyalty and satisfaction is extremely important. Net Promoter Score (NPS), measures customer experience and predicts business growth.

The purpose of this study is to understand which are the critical factors that affect customer satisfaction using the NPS methodology. The marketing literature recognizes 11 factors that determine customer experience (ex. pricing). Our goal is to identify these factors automatically in the text related to the open-ended question answered by the customers using deep learning, multilabel classification, and Natural Language Processing (NLP) techniques. Our second goal is to identify which factors have a higher impact on the customer experience.

Our dataset consists of 25,943 customer survey responses related to 39 service companies in 13 different industries. For all these instances, the open-ended questions were manually labeled, identifying a maximum of three of the 11 drivers per response. Based on this information, we constructed a deep learning model that was able to identify these drivers accurately on a test set. Finally, conclusions and recommendations on improving service quality are provided in this work.

3 - Profit-driven design of multisegment retention campaigns in a dynamic context with budget constraints
Juan Perez, Sebastian Maldonado

One relevant aspect to make firms' profit sustainable over time is to have a good consumer retention scheme; churn prevention is the critical activity in this regard. This duty requires effort in two main aspects, churn prediction and decision making. In our opinion, there has been intense research activity in churn prediction. Nevertheless, we believe that more research effort is needed on decision-making. The major decisions are on whom and when to apply retention campaigns. We propose a novel model to handle both decisions jointly, and we also include budgetary constraints and consumer segments. Our approach considers a nonlinear mixed-integer dynamic stochastic optimization problem, which we solve through a modified Particle Swarm Optimization Approach. The results evidence the relevance of budgetary constraints and the inclusion of stochastic approaches to produce more robust decisions. According to our literature review, prior research focused on consumers' segmented retention campaigns, but they did not consider dynamism nor budgetary constraints. We focus on these aspects, which we believe are relevant for firms decision-makers because they reflect real-world constraints and methodology challenges due to the model characteristics that make it hard to solve. Our preliminary analyses show the differences between our results and traditional approaches. We make explicit the benefits of modeling budget constraints in a dynamic context.

4 - Minimax Probability Machine with Regularization
Julio López, Sebastian Maldonado, Miguel Carrasco

We present novel second-order cone programming formulations for binary classification, by extending the Minimax Probability Machine (MPM) approach. Inspired by Support Vector Machines, a regularization term is included in the MPM and Minimum Error Minimax Probability Machine methods. This inclusion reduces the risk of obtaining ill-posed estimators, stabilizing the problem, and, therefore, improving the generalization performance. Our approaches are first derived as linear methods and subsequently extended as kernel-based strategies for nonlinear classification. Experiments on well-known binary classification datasets demonstrate the virtues of the regularized formulations in terms of predictive performance.

■ TE-34

Tuesday, 16:30-18:00 - Virtual Room 34

Combinatorial optimization for distribution and logistics I

Stream: Combinatorial Optimization
Invited session
Chair: *Claudia Archetti*

1 - Iterative Time Dilation Algorithms to solve Airline Schedule Design Problem
Ritesh Ojha, Natashia Boland

In this research, we extend the well-known Fleet Assignment Model over a time-expanded network. Key decisions in the model are represented by flight-arc variables, which determine the fleet type and departure time of an aircraft. Overall, these departures must meet given demand for every market (origin-destination airport pairs), and must satisfy airport operating hours, minimum inter-departure times, and overnight aircraft parking constraints.

Designing a schedule for even one major airline is an enormous undertaking. Our approach can provide a schedule for an entire airline network with around 100 airports and 1400 markets over a 7-day planning horizon, and a time discretization of 5 minutes. Since the scale of this network is far too large to obtain provably optimal solutions; we build on and creatively adapt recent advances in the dynamic discovery of time discretizations.

Starting with a small set of time intervals (which yields a coarse approximation), we iteratively refine our model using a non-uniform time-expanded network. We propose several refinement algorithms that attempt to generate only a small fraction of flight-arc variables, while yielding high-quality solutions. These algorithms utilize information from previous iterations to refine the set of departure time intervals. We evaluate the efficacy of these refinement algorithms to solve large scale airline schedule design instances, using a comprehensive computational study.

2 - Partially Flexible Demand Responsive Transit services
Oksana Sabinik, Hillel Bar-Gera, Tal Raviv

This study focuses on a partially flexible demand responsive transit (DRT) service for passengers who share one of their trip ends. We mathematically formulate the operational challenge of a DRT service of this type as the one-to-many DRT problem (DRT 1-M). The current study improves the formulations and the solution methods to enable addressing realistic size problems. A comparison between alternative dynamic programming algorithms is conducted in terms of efficiency and suitability for several variants of the original formulation. We consider the possibility of pre-planning a large set of routes for the entire service area instead of generating the routes only once the demand is known. From a computational point of view, pre-planned routes may allow faster response in real-time. From an operational point of view, pre-planned potential drop-off points may be desirable due to safety considerations. The contribution of the current study is in the methodological aspects as well as the operational aspect. The methodological aspects include mathematical formulations of relevant optimization problems, examining solution methods (algorithms and heuristics) and analyzing computational complexity. The operational aspects deal with testing the potential effectiveness and feasibility of this type of service, using a series of numeric experiments and statistical analyses, as well as analyzing the factors that affect the characteristics of the level of service.

3 - Optimization system for increasing efficiency of planning military deployment
Sofia Amador Nelke, David Raz

The Iron Dome system is an advanced technological system used by the IDF. It is characterized by the deployment of batteries in locations that change based on operational requirements. Deployment depends on a broad logistical support system: loading hundreds of containers, transportation using dozens of trucks, several deployment sites. In contrast with the technological and engineering innovation in the systems themselves, the logistical support for the deployment lags far behind, and it is carried out manually, using outdated methods which are slow and error-prone. This research seeks to optimize the process described above. The problem is complex and includes thousands of variables and tens of thousands of constraints. It was solved by modeling as an integer linear programming problem, followed by implementation of the solution and carrying out a case study based on real values, then carrying out an analysis and comparisons with the existing solution. The model was solved by the powerful Gurobi optimization solver. Analysis of the solution was carried out using several metrics and reference scenarios and indicates impressive performance gains in both running time and accuracy. The model shows real potential to create a new reality for the Iron Dome deployment system, as well as other systems deployed by the IDF, and for advancing academic research with the emphasis on the logistics of military deployment.

4 - The Fixed-Partition Policy Inventory Routing Problem
Claudia Archetti, Ali Diabat, Waleed Najy

In this paper, we formally introduce a variant of the inventory-routing problem (IRP) which we call the Fixed-Partition Policy IRP (FPP-IRP). In contrast to the classical IRP where delivery routes are arbitrary, the FPP-IRP partitions customers into mutually exclusive clusters that are fixed throughout the optimization horizon, and distribution is performed separately for each cluster. By restricting the flexibility inherent in the classical IRP, the FPP-IRP attains many potential advantages. First, partitioning reduces the operational complexity of the system and allows a simpler organization of the distribution service. Second, it improves the robustness of the system by isolating disruptions to affected clusters. Third, it can fit the needs and requirements of specific applications where consistency in the distribution policy, like familiarity between customers and drivers and route invariance, is required. We present two fixed-partition policies for the IRP together with mathematical formulations and valid inequalities. We also present a worst-case analysis on the performance of these policies. Extensive computational results are presented to show the behavior of these policies and glean insights into their potential benefits.

■ TE-35

Tuesday, 16:30-18:00 - Virtual Room 35

Game Theory, Solutions and Structures I

Stream: Game Theory, Solutions and Structures
Invited session
Chair: *Encarnación Algaba*

1 - Degree Centrality and Externalities in Networks
Agnieszka Rusinowska, Rene van den Brink

In this paper, we aim at incorporating externalities into centrality measures. We characterize axiomatically a class of measures based on the degree measure in weighted networks and modified for an externality. We give a foundation of these measures as utility functions over network positions, expressing preferences over positions in networks, and bringing externalities of connections between other positions. Other nodes being more connected can have positive as well as negative externalities. Our class of measures contains two parameters, in particular, an externality parameter. Depending on these parameters, we can recover some specific measures, e.g., the degree measure if the externality parameter is equal to zero. By considering some additional axioms on the preferences, we can specify the range for the parameters in the utility functions. Negative (respectively, positive) values of the externality parameter express negative (respectively, positive) externalities. Negative externalities of other nodes being connected to each other always occur when the sum of the values assigned to all nodes is a constant. This is the case, for instance, for the average degree externality measure which assigns to every node in a network its degree minus the average degree over all nodes, and therefore leads to the sum of the values equal to zero.

2 - Monotonicity in sharing the revenues from broadcasting sports leagues
Gustavo Bergantinos, Juan D. Moreno-Ternero

We explore the implications of the principle of monotonicity in the problem of sharing the revenues from broadcasting sports leagues. We formalize different forms of this principle as several axioms for sharing rules. We show that, combined with two other basic axioms (equal treatment of equals and additivity), they provide axiomatic characterizations of focal rules for this problem, as well as families of rules compromising among them.

3 - Marginalism, Egalitarianism and Multi-efficiency in Multi-Choice Games
Kevin Techer, David Lowing

The search for a compromise between marginalism and egalitarianism has given rise to many discussions. In the context of cooperative games, this compromise can be understood as a trade-off between the Shapley value and the Equal division value. In this paper, we investigate this compromise in the context of multi-choice games in which players have several activity levels. To do so, we propose new extensions of the Shapley value and the Weighted division values to multi-choice games. Contrary to the existing solution concepts for multi-choice games, each one of these values satisfies a core condition introduced in citegrabisch2007new, namely Multi-efficiency. We compromise between marginalism and egalitarianism by introducing the multi-choice Egalitarian Shapley values, computed as the convex combination of our extensions. In multi-choice games, it is possible to make a compromise at each activity level. Therefore, we propose subclasses of multi-choice Egalitarian Shapley values in which egalitarianism takes over marginalism for low activity levels (and vice-versa). To conduct this study, we introduce new axioms for multi-choice games. This allows us to provide an axiomatic foundation for each of these values.

4 - Influence in communication networks structures
Encarnación Algaba, Rene van den Brink, Zuzana Sasovova

In this paper, we focus on the most general networks reflecting communication called union stable systems and introduce a class of measures that all generalize the well-known degree measure for communication graphs, we give a characterization of this class and an application that cannot be studied with the tools existent in the literature.

■ TE-37

Tuesday, 16:30-18:00 - Virtual Room 37

Ethics, Societal Complexity and Governance

Stream: Ethics in OR
Invited session
Chair: *Dorien DeTombe*
Chair: *Cathal MacSwiney Brugha*

1 - Supporting government policy
Dorien DeTombe

The pandemic SARS-CoV-2 creates in disastrous situations. Governments are confronted with crucial changing situations. Suddenly many measures have to be taken. Where to turn to for help and support? The governments asked first advice to healthcare specialists. They gave advice, based on their own expertise, for a lockdown to save intensive care. Later economic experts were included. In many countries the government policy was not optimal, not effective and not efficient. A pandemic is a complex societal problem, including more aspects. Therefore the government should consult also people from the field of law, psychology, educational, psychiatry, and sociology. These people should exchange their knowledge in discussing the best interventions. A complex societal problem should be handled according to the guidelines of the field of Methodology of Societal Complexity. This scientific field advises to create Knowledge Institutes, advocated by the OECD in 2006, that are ready to act as soon as a complex societal problem arrives. Then based on the Compram methodology they can start inviting experts and actors to discuss the problem and to decide, based on their models of the problem, which changes would be the most fruitful and sustainable. This scientific advice could help the government in its decision. In this way decisions of the governmental are based on democratic sustainable scientific advice. Handling this way the governments could save lives, sorrow and money.

2 - Some thoughts about the covids19 pandemics as an ethical problem
Cor van Dijkum

Recently the world is confronted with an urgent complex societal problem: the fast spreading of a virus originated in China with severe consequences. It is a prototype of a complex societal problem the world will face in the future more and more. The question is how central institutions handle this problem and how successful they are at last. We can look on open access data that are available about the spreading of the disease for different countries expressing confirmed cases of contamination, people that became sick, deaths, recovered patients that became immune. We have to look at the way central institutions such as governments handled the problem, in first instance with non-pharmaceutical interventions such as lock-downs, following by pharmaceutical interventions with a strategy of administering vaccines to the population. Thereby we have to look at the disadvantageous societal side-effects of the lockdowns such as people losing their work, delayed treatment of people with other severe sickness, young people lagging behind in their education, and so on. The question is how to explore and balance the effects of pharmaceutical and nonpharmaceutical interventions in a scientific and ethical responsible way. To investigate the answers to that question we analyze available data, also with the aid of system dynamic models originating from a (SIR) model of spreading of a disease in a population.

3 - Combining Causal Loop Diagrams, Behavior-Over-Time Graphs, and Domain-Specific Languages to Structure and Explore Complex Problems
Adrian Stämpfli

Causal Loop Diagrams (CLDs) are a flexible and valuable tool for diagramming the feedback structure of systems. In strategic decision-making and management, we use CLDs to structure and explore complex problems, to foster learning, as a basis for simulation models, and to communicate simulation results. Often we combine CLDs with Behavior-Over-Time Graphs (BOTGs) as an initial step to understanding the dynamic patterns and the quantitative scale of the problem under study. BOTGs are especially helpful in capturing dynamic, quantitative hypotheses about the problem at hand.

We present a Domain-Specific Language (DSL) that allows generating visual representations of CLDs enriched with BOTGs. With the DSL, we can illustrate the structure, dynamic patterns, and quantitative scale of the problem under study step-by-step, allowing exploration and reflection by a broad audience.

The DSL approach lowers technical barriers and is accessible to modeling experts with little programming experience. A simple mechanism allows deploying the visual representations in the form of small web apps. We implemented the DSL in R, an open-source programming language and software environment designed for statistical computing, data science, and graphics, uniquely well suited to host DSLs.

A first application uses the DSL to generate small web apps showcasing CLDs and BOTGs of typical burnout-dynamics. Possible further developments include simulation capabilities.

4 - Examining the philosophical underpinning of public sector benchmarking
Eftychia Kessopoulou

Benchmarking has been observed to be more challenging than a purported reply to the budget, quality and time issues that modern public organisations face. Early publications, which are mainly practitioner-driven, transformed our thinking at the level of methodology but provide divergent conclusions on the utility and effectiveness of public sector benchmarking. To overcome this challenge benchmarking research requires a focus on the ontological, epistemological and axiological gaps pertaining to its study. This work reviews the literature by examine the ontological, epistemological and axiological underpinnings of public sector benchmarking. Moreover, it addresses the problems of traditional and contemporary public sector benchmarking approaches, concluding that though useful, they raise doubts about the necessity of determining and controlling contingent factors of benchmarking to change organisational performance, since these methods cannot explain why and how benchmarking-mediated performance change occurs.

■ TE-38

Tuesday, 16:30-18:00 - Virtual Room 38

Partnerships in medical and pharmaceutical operations during the COVID-19 pandemic

Stream: Humanitarian Operations
Invited session
Chair: *Fuminori Toyasaki*

1 - Citation Analysis and Mathematical Modelling of Partnerships Within the Pharmaceutical Industry
Abigail Richard, Fuminori Toyasaki

It is well-accepted that innovation has the potential to be greatly beneficial to firms. However despite the competitive advantage that innovation can provide, the innovation process tends to be risky. Resources invested in research and development (R&D) may be wasted if projects are unsuccessful. The pharmaceutical industry is no exception in this regard. In developing a new vaccine or drug, substantial investment is necessary, and there is no guarantee of fruitful results. As a consequence, it is important for firms to strategically consider potential avenues for innovation research, and selectively choose among plausible research objectives. This has been especially true during the course of the COVID-19 pandemic, where a race ensued among collaborative research teams to develop vaccines and treatments for COVID-19. To study potential innovation initiatives for research partners, we perform a patent citation analysis that brings to light some important considerations in the development of innovation goals. We model these considerations and their influence on innovation success.

2 - Capacity building for COVID-19 vaccines
Fuminori Toyasaki, Hongmei Sun, Ioanna Falagara Sigala

The COVID-19 pandemic causes a major paradigm shift in vaccine development and manufacturing. Many developers for vaccines against COVID-19 outsource their manufacturing process to other manufacturers, which is referred to as COVID-19 vaccine paradigm. The new paradigm raises a coordination issue on vaccine manufacturing capacity building between developers and manufacturers. We develop a game-theoretic model to analyze a developer's and a manufacturer's decisions about building production capacities before a vaccine receives regulatory approval. We find that the integrated traditional vaccine paradigm may outperform the COVID-19 vaccine paradigm under certain circumstances. To overcome this issue, we propose several countermeasures. We also find that both vaccine paradigms may not achieve a full production capacity due to the risks in vaccine development and approval. In response to this, our analysis suggests that vaccine buyers should pay a higher unit purchasing price to incentivize the capacity building. In addition, our work examines the impact of a possible ex-post negotiation for profit allocation after the approval of the vaccines on the vaccine developer's and manufacturer's decisions under the COVID-19 paradigm.

3 - Capacity management of vaccine production for sudden outbreaks of disease
Hongmei Sun, Fuminori Toyasaki

Timely capacity building and production for vaccines play a crucial role in containing sudden disease outbreaks. The recent COVID-19 pandemic, however, has revealed many shortcomings in capacity management and vaccine production, such as the non-coordinated decision-making between vaccine developers and manufacturers, and misaligned incentives in establishing production capacities for vaccine candidates before regulatory approval. Due to the coordination issue and misaligned incentives among different stakeholders, several authorized COVID-19 vaccines have been experiencing supply shortages due to insufficient capacities and/or production quantities. Through our literature analysis, we have noticed that little attention has been given to this research area, and our intension is to scope future promising research avenue in capacity management of vaccine production for sudden outbreaks. Employing mathematical models, our study analyzes the interactive decision-making of key stakeholders, which may largely affect the availability of vaccines and the welfare of people. Our model captures different uncertainties in vaccine development and production, such as uncertainties in demand, production yield, and receiving regulatory approval. Shedding light on vaccine production for sudden outbreaks, our work aims to fill the important gap in literature, as well as to provide managerial guidelines to facilitate a coordinated vaccine production in preparation for future possible pandemics.

4 - Mitigating disruptions in PPE supply chains in pandemics
Ioanna Falagara Sigala, Mikhail Sirenko, Gyöngyi Kovács, Tina Comes

The Coronavirus Disease (COVID-19) pandemic has emerged as an unprecedented health crisis worldwide and heavily disrupted and challenged the medical supply chain. This research empirically investigates the various forms of mismatches between supply and demand of Personal Protective Equipment (PPE) during the COVID-19 outbreak to propose mitigation policies to overcome them. Based on the empirical results, we develop a conceptual system dynamics (SD) model that highlights key feedback loops and the way policies impact them.

■ TE-39

Tuesday, 16:30-18:00 - Virtual Room 39

Healthcare logistics

Stream: Routing, Logistics, Location and Freight Transportation
Invited session
Chair: *Imadeddine Aziez*

1 - The home health care routing with electric vehicles and fast chargers
Çağrı Koç, Mehmet Erdem, Eda Yücel

We study the home health care routing and scheduling problem with time windows, electric vehicles and fast chargers. The problem aims to construct the daily routes of health care nurses so as to provide a series of services to the patients located at a scattered area. We aim to minimize the total cost, which comprises of total traveling cost of nurses, total cost of uncovered jobs, and total costs of recharged energy. We develop an adaptive large neighborhood search (ALNS) heuristic, which contains a number of advanced efficient procedures tailored to handle specific features of the problem. We conduct extensive computational experiments on new benchmark instances and assesses the competitiveness of the heuristic. Results have shown that the proposed ALNS is highly effective on the problem. Our analyses quantify the advantages of considering all charger technologies, i.e. normal, fast- and super-fast.

2 - The multi-period electric home health care routing problem
Osman Atilla Yazır, Tunahan Özmen, Çağrı Koç, Eda Yücel

We study the multi-period home health care routing and scheduling problem with homogenous electric vehicles and time windows. Some patients may require to be visited more than once in the same workday day and/or in the same workweek. We consider three charging technologies, i.e., normal, fast, and super-fast. The vehicles might be charged during the working day or at the end of the working day. A transportation cost should be paid when a nurse deposits her vehicle to a charging location at the end of the working day in order to charge it. The problem aims to construct the weekly routes of health care nurses so as to provide a service to the patients located at a scattered geographic area. The objective is to minimize the total cost of utilizing health care nurse, unit energy cost of using charger technology, fixed cost of utilizing a transfer service, and cost of rejecting a patient. We formulated a mathematical model and developed an adaptive large neighborhood search heuristic that has been efficiently crafted to handle the specific feature set of this problem. We conducted extensive computational experiments on benchmark instances in order to assess the competitiveness of the heuristic and to analyze the problem.

3 - The home health care routing with heterogeneous fleet of electric vehicles
Eşref Cebeci, Yağmur Ünal, Alican Yılmaz, Eda Yücel, Çağrı Koç

In this study, we work on the home health care routing and scheduling problem with time windows, heterogeneous electric vehicles, synchronized jobs, and fast chargers. The problem aims to establish daily routes and schedules for health care nurses to provide a series of services to patients located at a scattered area weighted by the number of patients. Each healthcare nurse should be assigned to an electric vehicle from a heterogeneous fleet of vehicles. We consider three different types of vehicles in terms of price, range, and energy consumption. We aim to minimize the total costs of energy consumption, utilizing nurses, and uncovered jobs. We mathematically formulate the problem and develop a greedy randomized adaptive search procedure (GRASP) heuristic that includes a series of advanced efficient procedures designed to specifically address the problem. Computational experiments are conducted on benchmark instances to analyze the problem in detail and to assess the performance of the GRASP.

4 - Fleet sizing and routing problem with synchronization for AGVs with dynamic demands
Imadeddine Aziez, Jean-François Côté, Leandro Coelho

Transportation activities within hospitals are becoming more complex due to the expansion of the number of materials and equipment used. One of the most powerful ways of achieving more efficiency of transportation systems in hospitals is via using automated guided vehicles (AGVs). In this paper we study the fleet sizing and routing problem with synchronization for AGVs with dynamic demands (FSRPS-AGV). The goal is to simultaneously optimize the number and types of carts and AGVs needed to perform all daily requests in a hospital. Each request is composed of several tasks consisting of moving material from a pickup point to a delivery point using different types of carts. Operation synchronization among the tasks of the same request and movement synchronization with respect to AGVs and carts are major challenges. In this paper, we introduce a mathematical formulation and propose a powerful matheuristic for the FSRPS-AGV. The algorithm is based on a fast and efficient dynamic reoptimization of the routes upon the arrival of new requests. We compare the performance of our matheuristic under different scenarios, showing that it can handle dynamism of demand very well and achieve near-optimal solutions. We assess our methods using small and large instances generated based on real data from an industrial partner. Finally, we provide managerial insights with respect to the number of AGVs and carts that should be acquired by our industrial partner.

■ TE-40

Tuesday, 16:30-18:00 - Virtual Room 40

Mixed-Integer Programming for Resource-Constrained Project Scheduling

Stream: Scheduling and Project Management
Invited session
Chair: *Tamara Bigler*
Chair: *Norbert Trautmann*

1 - A Matheuristic Approach for the Multi-Site Resource-Constrained Project Scheduling Problem
Tamara Bigler, Mario Gnägi, Norbert Trautmann

The multi-site resource-constrained project scheduling problem (multi-site RCPSP) is an extension of the classical RCPSP. As in the classical RCPSP, precedence-related project activities that require renewable resources for their execution must be scheduled such that the total project makespan is minimized. In addition, activities can be scheduled at different sites. While some resource units are permanently located at one site, others can be transferred between sites. If a resource unit must be transferred to another site or if the output of an activity must be transferred to another site, transportation times arise. In the literature, a discrete-time and a continuous-time mathematical model as well as several metaheuristics have been introduced for this planning problem. We propose a matheuristic that iteratively—with a rolling horizon—schedules a changing subset of activities by solving a variant of the continuous-time model from the literature. In each iteration, different sets of binary decision variables are relaxed (to take a value between 0 and 1) or fixed (to their values from the previous iteration). We applied the matheuristic to standard test instances from the literature. It obtains high-quality solutions and is able to derive a considerable number of new best known solutions.

2 - A Mathematical Model For Unrelated Parallel Machine Scheduling Problem With Additional Resources
Özgür ŞaŞtim, Servet Hasgul

This research addresses an unrelated parallel machine scheduling problem with additional resources, setup times, and machine eligibility constraints. Especially where the processing and the setting up of jobs on the machines require additional resources. The resources such as labor, tools, fixtures, and industrial robots are not only required for processing, setup, loading/unloading jobs but also restricted. Majority of the traditional scheduling problems in unrelated parallel machine environment considers the machine as the only resource. Considering additional resources, machine and sequence-dependent setup time, and machine eligibility constraints make the scheduling problems more realistic and practical for implementing in the manufacturing environment. To formulate this complicated problem, a new mathematical model is proposed. Due to the complexity of the model, a metaheuristic such as simulated annealing is developed for its solution. The solving performance of the proposed methods was tested using randomly generated instances.

3 - Examination of fairness in final exam scheduling
Szilvia Erdős, Bence Kovari

Throughout time, the topic of fairness has emerged in scheduling problems, but the equal distribution of all participant's workloads is usually in focus. However, this topic is way more complicated when dealing with NP-complete problems.

As here, the optimisation criterion is defined as the distance of the elements of a homogenous group; however, in case of combinatorial optimisation problems, like in multiple-participant schedulings, the fairness should be taken under consideration between different heterogeneous groups too. The method of definition of which is not completely clear, thus in literature, there have been many approaches.

During our researches, we used mathematical approaches to define the fairness as the distance between different groups in final exam scheduling. Which is a special subtask of scheduling problems, where special requirements can restrict the state space, and they can sometimes even contradict each other.

We found a method based on the Lipschitz-criteria, which may contribute to fairer schedulings in real problems. Meaning, it is capable of giving fairness between heterogeneous groups with different constraints (e.g., presidents, examiners, supervisors).

The work presented here has been carried out in the frame of project no. 2019-1.1.1-PIACI-KFI-2019-00263, which has been implemented with the support provided from the National Research, Development and Innovation Fund of Hungary, financed under the 2019-1.1. funding scheme.

4 - Mixed Integer Linear Programming for a real-world parallel machine scheduling problem with workforce and precedence constraints
Giulia Caselli, Manuel Iori, Maxence Delorme

Scheduling the activities of engineering testing labs is a complex and time-consuming task, mainly due to the high customization and variable demand of tested products and the required technical knowledge. In this work, we consider a real-world scheduling problem occurring in the engineering testing lab of a multinational company producing hydraulic components for automation and being located in Italy. Similar problems have been solved in the literature under the framework of resource constrained parallel machine scheduling problem. In our work, the tests on the hydraulic components of product prototypes are the jobs to be scheduled. Each job must be processed on a machine and requires an additional human resource to prepare the machine and supervise the job. The aim is to minimize the total weighted tardiness. Additional constraints make our problem new for the literature. Release and due dates are given for jobs. Each job has a processing time expressed in working days that depends on the machine and requires a daily occupation for workers in terms of hours per day, given the daily availability of workers. Moreover, precedence and contiguity relations between jobs must be respected. We propose a Mixed Integer Linear Programming formulation to model the problem and test it on a set of real-world and randomly-created instances. Future studies will be devoted to the development of heuristic and metaheuristic procedures.

■ TE-41

Tuesday, 16:30-18:00 - Virtual Room 41

Mobility Algorithms and Services

Stream: Timetabling and public transport
Invited session
Chair: *Chistos Zaroliagis*

1 - Rewarding Schemes for Crowdsourced Parking Ecosystems
Anastasia Maria Kampyli, Spyros Kontogiannis, Chistos Zaroliagis

Limited parking space in urban environments has a severe social and environmental impact, because of time loss and unnecessary pollution while looking for free parking spots. In a recent effort, we have developed the SocialPARK ecosystem to tackle this problem through the activation of a community of interacting citizens, parking companies and municipalities, towards a mutually profitable management of the publicly available parking space. The goal is to create an integrated platform for the provision of personalized parking functionalities as a service, auditing parking availability information through a crowdsourcing approach that gathers availability information provided by commuters, parking vendors and municipalities. In this context, a central challenge in delivering trustworthy parking services is to ensure a truthful behavior of the involved stakeholders: how to obtain high quality truthful information, given that it is provided by possibly unreliable users. Towards this direction, we present two rewarding schemes that provably incentivize users to behave truthfully. Both schemes are based on virtual credits (points) that users earn for providing parking-availability information. The first scheme is based on a simple static approach, where users receive points for behaving truthfully that are devaluated with time. The second scheme is based on a dynamic approach, in which users may also spend points for acquiring parking-availability information by the ecosystem.

2 - New Graph-based Approaches for Multi-Modal Route Planning
Paraskevi-Maria-Malevi Machaira, Spyros Kontogiannis, Andreas Paraskevopoulos, Chistos Zaroliagis

A multimodal journey planner is a key component of any modern mobility service, as it computes optimal journeys from any origin to any destination using a multitude of transport modes (bus, metro, train, tram, walking, electric cars, bicycles, etc) under various optimization criteria (typically earliest arrival-time and minimum number of transfers), or a combination of optimization criteria (giving rise to multi-criteria optimization problems). The state-of-the-art approaches can be broadly classified into array-based models and graph-based models. The former represents timetable information as an array, while the latter as a graph. Array-based models have shown to be very effective in terms of query time, while graph-based ones usually answer queries by computing shortest paths, and hence they are suitable to be combined with the speed-up techniques developed for road networks. Although array-based models exhibited very fast query times, recent work has shown that appropriate graph-based models compare favorably with array-based ones in query times and perform extremely well in updating the timetable information after a delay. In this work, we present two such recent graph-based models for computing optimal multimodal journeys under single or multiple optimization criteria. Both models are not only query and update time-efficient, but also space-efficient and model realistic multimodal journey scenarios where changing transport vehicles does not take negligible time.

3 - Relocation Schemes in Free-Floating Car-Sharing Systems
Damianos Kypriadis, Charalampos Konstantopoulos, Grammati Pantziou, Damianos Gavalas

Vehicle Sharing Systems (VSS) have a positive impact on urban mobility, alleviating traffic congestion and its environmental footprint. However, the common mismatch between demand and offer occurring in VSS requires relocation of vehicles among areas by the VSS personnel to meet user demand. In this paper, two relocation schemes in Car Sharing Systems are presented. Specifically, the first scheme proposes algorithmic solutions to the Static Relocation Problem (SRP), where the relocations are performed during the night when the system is idle, whereas the second one deals with the Dynamic Relocations Problem (DRP) i.e., the relocations are performed with the system serving users at the same time. Both schemes employ a number of drivers who undertake the relocation of a set of cars from areas with surplus of cars to those with deficit. Each driver's relocation plan comprise alternating phases of a car relocation followed by walking to the next car to be relocated. Auxiliary cars driven by additional drivers are employed to facilitate the drivers performing the relocations, by transferring them among car drop-off and pick-up locations. The objective of the SRP is the complete rebalance of the car distribution across the deployment area, whereas that of the DRP is the maximization of the number of performed relocations, since perfect rebalance might not be always feasible due to time constraints. In both cases, walking in the drivers' routes is also minimized.

4 - Multi-destination, multimodal tourist trip planning
Charalampos Konstantopoulos, Nikolaos Vathis, Grammati Pantziou, Damianos Gavalas

The Vacation Planning Problem (VPP) is an optimization problem whose objective is to find an ordered set of destinations in a specific region, propose a number of days to stay at each destination and decide upon ordered visits to points of interest for each day. The goal is to propose daily itineraries of POIs that maximize the satisfaction of a tourist while respecting the inherent constraints to the problem, such as the opening hours of each POI and public transportation timetables, as well as the tourist-induced constraints such as preferences over each type of POI, time allotted per day to visit points of interest, preferred means of transportation and manual changes to the proposed solution such as blacklisting POIs, reordering visits and choosing a specific hotel to stay at each destination. VPP comprises an extension to the Tourist Trip Design Problem and, thus, to the Orienteering Problem, since it not only suggests daily itineraries, but also optimal destinations and optimal distribution of days for each destination. As such, it is NP-hard and cannot be reasonably solved to optimality. Thus, we present heuristic approaches for solving the VPP that are based on battle-tested ways to solve the Orienteering Problem, arguing about the characteristics of each heuristic approach. In addition, we present experimental results that show the quality, practicality and efficiency of each approach. This work has been partly supported by the University of Piraeus Research Center.

■ TE-42

Tuesday, 16:30-18:00 - Virtual Room 42

Computational Intelligence in Social Sciences

Stream: Modelling and Simulation of Social-Behavioural Phenomena in Creative Societies
Invited session
Chair: *Nitin Agarwal*

1 - Operational Research Behind Social-Behavioural Phenomena in Creative Societies
Leonidas Sakalauskas

The applications of OR techniques to business launched an effective development of OR as a scientific discipline. Recently, however, there have been a growing number of systemic social challenges, because society creates a set of social behavioural phenomena whose knowledge of mechanisms is essential for building a sustainable society. We aim to review the operationalisation of such phenomena as the expression of logical and verbal communication for the efficient understanding of their essence and relevant decision-making, thus bridging OR with social sciences and humanities. The creation of the operationalisation paradigm on the basis of the theory of structural equation modelling, multi-agent modelling and game theory, together with data science and mathematical sociology methods, allows the development of data-driven operationalisation for evidence-based solutions. It should be stressed that solving problems related to the social-behavioural phenomena must encompass different types of intelligence without distinguishing logical and verbal intelligence. Such an approach would exclude discrimination by type of intelligence and ensure tolerance for different ways of perception, thus laying the foundation for a future society that must be creative (Florida, 2002). Thus, we must be creative in order to remain at the forefront in the fight against undergoing and coming systemic social challenges (Maculan, 2020; Speranza, 2020).

2 - Applying epidemiological model to evaluate and compare the propagation of misinformation and legitimate hashtags related to COVID

Maryam Maleki, Esther Mead, Nitin Agarwal

Examining the information propagation on social media platforms like Twitter allows us to understand the attributes of underlying media and model the patterns of people communication. The epidemiological models provide a mathematical model to understand the dynamics and trends of the propagation of different kinds of information. The foundation of the epidemiological models is based on dividing the population into various components that represent the state of each individual in the social media platform. Different epidemiological models have various components and users move from one compartment to another with specific probabilities that should be estimated from the data. To apply the epidemiological model, we used Twitter data related to COVID-19 for the entire 2020. We collected data for different legitimate and misinformation hashtags which can best cover a broad range of topics related to COVID-19 including mask, lockdown, vaccine, etc. Applying the epidemiological models for evaluating the spread of legitimate and misinformation hashtags can help us understand and compare diffusion trends of different kinds of information. This evaluation can provide an opportunity to create appropriate strategies to control the propagation of misinformation on social media platforms.

3 - Towards a Multi-method Socio-Computational Approach for Analyzing Toxicity Propagation Among User-generated Discourse about COVID-19 on YouTube

Nitin Agarwal, Ruchi Agarwal, Karen DiCicco, Esther Mead

As COVID-19 spreads across the globe, formal recommendations from medical experts are becoming muffled by the avalanche of toxic content posted on social media platforms. This volume of toxic content prevents the dissemination of important and time-sensitive information and jeopardizes the sense of community that online social networks seek to cultivate. In this study, we present techniques to analyze toxicity and propagating actors on YouTube during the initial months after COVID-19 information was made public. Our dataset consists of 544 channels, 3,488 videos, 453,111 commenters, and 849,689 comments. We identified dominant topics and evolving trends by applying topic modeling using Latent Dirichlet Allocation. Influential commenters were identified using social network analysis (SNA). Toxicity analysis was conducted to ascertain overall network health. SNA allowed us to identify the top toxic users in the network that allowed a controlled environment simulation experiment where impact of removal of certain users was evaluated on the overall health of the network. Findings from our study demonstrate its utility to researchers, social media companies, and policymakers alike benefiting both science and society.

■ TE-43

Tuesday, 16:30-18:00 - Virtual Room 43

OR in Sports

Stream: OR in Sports
Invited session
Chair: *Frits Spieksma*

1 - Analysis of Olympic Events, Superstars, Technology, Techniques Training and Women's Competition in Ancient Greece

Raymond Stefani

Starting in 776 BC, the Olympic Games are the best documented of the four Panhellenic Games. A list of 861 Olympic events and winners is analyzed. There were events in athletics, combat sports, chariot racing, equestrian racing and artistic performances. The Games spawned technology such as the clever use of ropes and levers to start the runners and the chariots. A cord was wrapped around the javelin with a finger loop to create spin stabilization. Long jumpers employed complex kinematics while carrying weights which added about 5%. Training and nutrition are discussed. Performance-enhancing drugs were allowed. The three greatest superstars were Leonides of Rhodes who won three running events, four times in a row (12 wins), Herodoros of Megara who won the trumpeter competition nine times in a row and Astylos of Kroton who won 7 athletics events. Although the Olympic Games were only open to men, Kyniska of Sparta, a married woman, was a double Olympic champion, as owner of the horses and trainer of the drivers that won two chariot races. Women competed at Olympia in their own Heraea Games. The Olympic flame is now lit at Hera's shrine, symbolizing the equality of women.

2 - Would the fastest be the last when choking under pressure matters? Evidence from relay contests

Nikolai Avkhimovich

Sportsmen tend to choke in decisive moments (e.g. when a competitor is too close): the "choking under pressure" effect has been observed in different areas. Based on modelling and empirical evidence of relay races, we will observe, whether coaches are able to manage that factor through changes in sequence of players and whether changes in sequence of players in relay race could impact the probability of winning.

3 - Filling a theatre in times of corona

Frits Spieksma, Danny Blom, Rudi Pendavingh

All around the world, the corona-crisis has hit the cultural sector hard. Different countries, or regions, have imposed different rules in an attempt to stop the spread of the virus. Clearly, these rules have a dramatic impact on the operation of any theatre, and despite governmental efforts, many theatres are struggling to survive.

Motivated by a practical application, we introduce an optimization problem that deals with the economical consequences of the measures taken in the context of the COVID-19 pandemic. More specifically, we investigate the problem of maximizing the number of guests in a theatre hall that respects social distancing rules. We establish a correspondence between solutions of this problem and so-called trapezoid packings. Using this correspondence, we phrase our problem as an integer program, and use IP-solvers to solve the corresponding models. Our findings indicate that up to 40% of the normal capacity can be used for a single show setting, and up to 70% in case artists opt for two consecutive performances per evening. We also consider the impact of solutions that allow for an efficient handling of the guests. These insights, together with other innovations, offer hope for theatres to remain competitive.

■ TE-44

Tuesday, 16:30-18:00 - Virtual Room 44

Making it happen: ways of overcoming challenges of deployment

Stream: Practice of OR (Making an Impact)
Invited session
Chair: *Ruth Kaufman*

1 - Overcoming challenges in deployment of OR projects
Max Moullin

Overcoming Challenges in Deployment of OR Projects.

Ensuring that OR projects actually get implemented and lead to successful change is not an easy task and requires careful thought. This 40-minute workshop will discuss how to overcome some of the challenges practitioners face in ensuring deployment, illustrating this with actual case studies. It will discuss staff and stakeholder involvement, addressing organisational and behavioural factors as well as processes, using problem structuring methods alongside other OR approaches, integrating risk management, working across organisational boundaries, getting involved in strategy, processes and performance measurement, and helping the client and stakeholders develop a culture of innovation and learning rather than a top down blame culture.

The workshop will also show how these factors are incorporated in the Public Sector Scorecard, a problem structuring and performance management framework for the public and third sectors which has been used in six continents. This has three phases: strategy mapping, service improvement and performance measurement. It aims to help organisations focus in turn on the outcomes desired, the processes that lead to those outcomes, and capability - the organisational, people and resource issues that are required to support staff and processes in achieving those outcomes. Several case studies using the Public Sector Scorecard will be described.

2 - The View from ORTEC
Meike de With

Often, creating an OR model is only a small part of the work that we as consultants do for our customers, and ensuring the customer will actually use the model is much more work (and much more important) than getting the optimal result.

There are many reasons why people might choose to continue their old tools or do things manually, even though the new model gives a more optimal (cheaper, faster, etc) result. For example, they are simply used to the old way of doing things, they do not trust the new application, they do not want to invest the time (or they do not have time) to get to know and test the new tool, or even that it is less easy to manipulate the new application if they for some reason want to get a certain result. In addition, there are also other challenges in deployment, for example lack of (correct) data.

During this session, we will discuss these challenges (and others), discuss methods to deal with this, and look at a number of real-life examples where deployment was successful or not so successful, and why.

■ TE-45

Tuesday, 16:30-18:00 - Virtual Room 45

OR in Natural Resources / Forestry

Stream: Specific Applications of OR in Agriculture, Forestry and Fisheries
Invited session
Chair: *Lidija Zadnik Stirn*

1 - Contributing Factors to Land Valuation: Using AHP to Inform Economic Development in Legacy Cities
Ellen Szarleta

Recent developments and trends in many urban areas, specifically legacy cities, raise important questions regarding future economic growth. Legacy cities have experienced significant population and job loss, resulting in high residential vacancy and diminished service capacity and resources. Thus, policymakers, business, and nonprofit organizations are exploring strategies for enhancing workforce development, attracting business, reducing crime, and securing fiscal sustainability.

Cities can fuel economic growth using a variety of mechanisms, including revenues obtained from property taxes. This project examines the factors contributing to the perceived value of land using the AHP method. The purpose is to identify contemporary factors and their relationship to both the nature and value of land and structures. Public decision-makers, informed by the results, are empowered to discuss and deliberate on the best means of ensuring the system works fairly and efficiently to support thriving communities. The project identified four categories of factors influencing land values: economic, physical, social, and government. Experts in assessment, property appraisal, and policy administration contributed to analyzing each factor category's relative importance.

2 - An Iterated Local Search Metaheuristic for Fire Suppression
Filipe Alvelos, André Bergsten Mendes

We consider the problem of, given a landscape and a fire ignition location, deciding where to locate the available fire suppression resources in order to minimize the burned area. We address this problem by using a grid representation of the landscape, by considering that the resources become available at given time instants and assuming that the fire propagation follows the minimum travel time (MTT) principle. When a resource is assigned to an unburned node, it becomes protected and delays the fire propagation to its adjacent nodes. A solution method is proposed to solve this problem based on an iterated local search metaheuristic. It comprises a probabilistic constructive heuristic that assigns resources to nodes and a local search scheme that relocates one or two of the resources to other nodes. The problem is very challenging, as the Dijkstra's shortest path algorithm must be called to determine the fire arrival time at each node of the grid each time a new resource configuration is assessed. Computational tests were made on grids with up to 2,500 nodes, which are of realistic size. The ILS performance is compared to optimal solutions obtained by MIP exact model solved in Gurobi for randomly generated grids with up to 400 nodes.

3 - Stratification modelling for waste variation in different areas
Vlastimír Nevrlý, Milos Kopa, Radovan Šomplák

Waste composition is the crucial parameter for targeting policies and promotions in waste management. Areas have a diverse population structure and urban character, which significantly changes the differences in the production of individual types of waste. The differences might be explained by correlated variables, which are unknown and can only be estimated. A long-term survey, which takes into account the variation during the year, should be carried out to obtain estimates of the waste composition. These studies are costly and cannot be performed in all areas. For such purposes, stratification techniques are used to select representative samples to obtain the most accurate results. However, general stratification procedures do not take into account the specificities of waste management, and tailor-made approaches should be proposed. This paper deals with possible approaches and demonstrates them in a case study. In addition to defining the optimal areas for conducting the investigations on waste composition, the output identified fundamental boundaries of the presented problem.

4 - Operational risk management in Aquaculture by Multistage Stochastic Programming
Benjamin Narum

The Aquaculture industry is capital intensive due to long lead-time of the biomass before it can be harvested. There are significant stochastic risk factors which may cause considerable increased mortality in the biomass, resulting in large monetary losses. A portfolio can be of significant size with complicated effects from both biological and market considerations which creates the need for decision support tools. We present a spatial time series forecasting model using state of the art climate models to predict development of decision relevant factors on farms along the Norwegian coastline. This, in turn, is used in a multistage stochastic programming model to support effective operational management of biomass portfolios.

■ TE-46

Tuesday, 16:30-18:00 - Virtual Room 46

Data Envelopment Analysis

Stream: Data Envelopment Analysis and Performance Measurement
Invited session
Chair: *Andreas Georgiou*

1 - Efficiency analysis with unobserved inputs: An application to endogenous automation in railway traffic management
Dieter Saelens, Marijn Verschelde, Laurens Cherchye, Bram De Rock, Bart Roets

Performance analytics are commonly used in decision making, but vulnerable to an omitted variable bias (OVB) issue when there is incomplete data on used production factors. In this paper, we relax the standard assumption in efficiency analysis that all input quantities are observed and develop a nonparametric method robust to endogeneity. Our method extends Cherchye et al., 2018 by introducing cost inefficiency in a nonparametric framework to recover unobserved heterogeneity of cost minimizing firms. We bridge the OR literature with the ECON literature by addressing the critique of Stigler, 1976 on the concept of inefficiency (Leibenstein, 1966) that found inefficiencies reflect unobserved inputs rather than waste. As such, we are the first to differentiate between cost inefficiency (i.e. waste) and unobserved input usage (i.e. optimally chosen inputs unobserved to the analyst). A MC simulation shows that our method nicely recovers cost inefficiency and unobserved input use under endogeneity. We illustrate the approach by studying cost efficiency and endogenous automation in a real-world dataset on Belgian railway management control rooms. Our findings cast doubt on Stigler's argument showing instead the existence of inefficiencies that cannot be attributed to use of unobserved inputs or environmental factors. Moreover, we document how the OVB impacts cost efficiencies of individual observations in a dissimilar way in case the use of unobserved inputs is not controlled for.

2 - Infonavit efficiency index: analysis with DEA
Alejandra Chávez García

Infonavit (National Housing Fund for Workers) is the largest mortgage company in Latin America, managing more than 62 million housing accounts equivalent to 1,13 billion Mexican pesos which is equivalent to about 6.5% of Mexico's GDP (USD 59.9 billion). In a long-term perspective, efficiency implies profit maximization and cost minimization. In the short term, efficient Infonavit areas can obtain extraordinary benefits if they carry out their activities with the minimum possible resources or in the shortest possible time. This paper consists of an approach through the Data Envelopment Analysis methodology for the determination of efficiency indexes in six areas of Infonavit and a global index. First, the six areas were considered separately to use their variables to construct their own analysis. Subsequently, the requested budget was broken down and compared to the general expenditure to measure the efficiency of the expenditure. Human, technological and material resources are contemplated so that workers can carry out their activities, but it is intended to be done efficiently. Several tests were used to compare the performance and identify factors that contribute to the efficiency and to build the areas indexes and to replicate the Infonavit efficiency index with DEA methodology.

3 - Efficiency evaluation in Markov manpower planning using Data Envelopment Analysis
Andreas Georgiou, Emmanuel Thanassoulis, Alexandra Papadopoulou

This presentation introduces a new approach in analyzing the efficiency of manpower policies in markov models using Data Envelopment Analysis. The well-known attainability problem is revisited and various recruitment or promotion policies are investigated under variable returns scale. The approach is based on the Benefit of the Doubt formulation of DEA models with constant output or input and the alternative policies are treated as Decision Making Units. Apart from the notion of technical efficiency allocative efficiency is also investigated by introducing various forms of mobility costs into the model. The paper concludes with a numerical illustration and ideas for further research.

4 - Knowledge flows and Learning. Are there any role models?
Nikos Chatzistamoulou, Kostas Tsekouras, Kostas Kounetas

Over the years literature on benchmarking has accumulated theoretical developments as well as empirical evidence on the performance of production entities for a broad spectrum of circumstances. However, we should not neglect that the nature of benchmarking encompasses a learning perspective which has been totally overlooked, despite that peers might affect learning. In this paper, a heuristic algorithm is introduced based on Data Envelopment Analysis that identifies the most influential units of a technology set and through generating benchmarking periods by drawing the former, we investigate whether knowledge flows affect the performance growth of the rest of the units. The extent of spillovers is considered by investigating the reference production entity's performance improvement. Moreover, we create a new benchmarking set including the most influential units to explore which benchmarking period conveys the strongest knowledge flows. By integrating the concept of the most productive scale size, the most influential unit exploiting scale effects is identified. Findings indicate that the algorithm works, as knowledge flows enhance the mean performance of all units as well as that of the reference unit up to the third period. Evidence suggests that the most productive scale size is unique, since only one of the influential units manages to exploit scale size.

■ TE-47

Tuesday, 16:30-18:00 - Virtual Room 47

MINLP Software

Stream: Mixed-Integer Nonlinear Optimization
Invited session
Chair: *Ruth Misener*
Chair: *Jan Kronqvist*

1 - Non-Convex MIQCP in Gurobi: New Advances
Tobias Achterberg

Since version 9.0, Gurobi is able to solve non-convex quadratically constrained mixed integer programs (MIQCPs) to optimality. But with our new version 9.1, we achieved pretty significant performance improvements for models of this problem class.

This talk will summarize the algorithmic ingredients that lead to these improvements and explain some of them in more details.

2 - Recent advances in the BARON project
Nikolaos Sahinidis

The BARON project has been addressing the global optimization of NLPs and MINLPs since the early 1990s. In this talk, we review key steps in the history of BARON, and present recent developments, including computational results on benchmarks and applications.

3 - Global Optimization in Reduced Space
Alexander Mitsos, Jaromil Najman, Dominik Bongartz

We present on theory, algorithms and applications of reduced-space formulations for the deterministic global optimization of mixed-integer nonlinear problems. We first theoretically discuss reduced-space vs. full-space formulations as well as convex relaxations based on multivariate McCormick relaxations, with vs. without auxiliary variables. In particular, we discuss possibilities for propagating linearizations efficiently. We then discuss our software "McCormick-based Algorithm for mixed-integer Nonlinear Global Optimization (MAiNGO)", including its parallelization capabilities. We finally demonstrate the advantages of our proposed approach for problems from process systems engineering, in particular from flowsheet optimization.

4 - Solving nonconvex MINLP problems with SHOT
Andreas Lundell, Jan Kronqvist

In this presentation, we discuss some recent enhancements to the mixed-integer nonlinear programming (MINLP) solver SHOT. SHOT is an open-source solver that was originally designed to solve convex problems. In recent versions, however, the functionality for solving also nonconvex problems has been significantly improved. Using convexity detection on the individual functions in the (nonconvex) MINLP problem, SHOT can now return a valid bound on the objective function value also for nonconvex problems. If this bound is not small enough to certify a global solution, heuristic procedures for finding good solutions without global certificate can also be used. Another feature discussed in this presentation is automated reformulations for nonconvex functions, which can through lifting transformations, convexify certain types of problems. The new nonconvex functionality is benchmarked against other local and global MINLP solvers, to show how SHOT compares with the state-of-the-art.

■ TE-48

Tuesday, 16:30-18:00 - Virtual Room 48

Stochastic Lot-sizing

Stream: Lot Sizing, Lot Scheduling and Production Planning
Invited session
Chair: *Safia Kedad-Sidhoum*
Chair: *Duygu Tas*

1 - MILP Approximation for non-stationary stochastic lot-sizing with lateral transshipment
Xiyuan Ma, Roberto Rossi, Thomas Archibald

This paper addresses the two-stocking locations single item non-stationary stochastic lot-sizing problem. The inventory level at each location is reviewed periodically. Items can be reordered from a common warehouse and can also be transshipped laterally from the other location. Lateral transshipment is assumed to be proactive to re-distribute the stock between two stocking locations. Therefore, the order of action in each period is: transshipping, reordering and satisfying the demand at each location each installation. The costs are imposed on transshipping, ordering, holding, and backordering. The key issue in such systems is to determine the quantity of the lateral transshipment between depots and the order quantity from the warehouse. We formulate the problem via stochastic dynamic programming to minimise the expected total cost. Since the number of actions increases exponentially as feasible quantities of transshipment and replenishment grow, we develop an equivalent two-stage dynamic programming to improve computation efficiency. We describe the (near-)optimal policy according to the stochastic dynamic programming and develop the stochastic programming for the problem, based on which, we introduce a mixed integer non-linear programming that applies piecewise-linear approximation of the cost function to compute near-optimal parameters for a broad class of problem instances. Numerical experiments are implemented to verify the accuracy of the approximation method.

2 - Inventory decisions for ameliorating products under consideration of stochastic demand
Marjolein Buisman, Sonja Rohmer

Product quality is a key factor in the food and drinks industry, allowing companies to distinguish themselves from their competitors and achieve higher profit margins. The quality of a product may, however, be subject to change over time and thus complicate planning and decision-making processes. While most of the literature in this area focuses on quality change in the form of deterioration, there are also products that improve in quality over time, resulting in unique challenges with regards to production and inventory management. In this context, this paper introduces an inventory planning problem for the case of ameliorating products under consideration of demand uncertainty as well as product loss due to evaporation over time. The proposed model is illustrated on two case studies from the cheese and whisky industry and used to investigate different scenario settings. In these settings, we explore the impact of the length of the considered planning horizon, the level of demand uncertainty involved, the available capacity and different penalty costs for unfulfilled customer demand. The general findings show that the differences in profit margins between the quality categories influence the optimal strategy of the manufacturer.

3 - Solving a capacitated lot sizing problem with stochastic production and setup times
Duygu Tas

We study a capacitated lot sizing problem where both production and setup times are stochastic. The aim of this problem is to minimize the total cost that includes two main components: the regular production costs and the expected overtime costs. We first develop an exact procedure to compute the expected overtime for a given production and setup plan. Then, we propose a solution approach based on tabu search algorithm to effectively solve the problem. This approach includes three main phases that are initialization, improving and scheduling. The numerical experiments are conducted on well-known problem instances, and the performance of the proposed approach is validated by using the lower bounds reported in the literature. We also provide comprehensive analyses on the numerical results in terms of the computational time and the solution quality. These analyses show that the proposed procedure obtains very good solutions in a reasonable amount of time.

■ TE-51

Tuesday, 16:30-18:00 - Virtual Room 51

OR in Aviation 2

Stream: OR in Aviation
Invited session
Chair: *Vikrant Vaze*

1 - Penalized Information Relaxation Bounds for Dynamic Decisions on Time-Space Networks
Lavanya Marla

The dynamic management of large-scale service networks has motivated the development of a number of algorithms that re-configure or repair such networks at the operational, tactical and near real-time scales. These algorithms re-allocate resources across the networks as information about demands, service times or disruptions is revealed over time. Performance evaluation frameworks for these algorithms, on the other hand, are nearly always based on offline or omniscient bounds for these systems. In this paper, we present a novel methodology to construct tighter performance bounds for dynamic resource allocation problems modeled on time-space networks. Specifically our approach expands upon the theory of penalized information-relaxation bounds developed by Brown et al (2010) to the setting of large-scale network-based resource allocation, by avoiding the need to compute penalty functions for each possible state of the system. We apply our approach to a large-scale airline disruption management problem and demonstrate that our new bounding approach improves upon existing omniscient bounds and allows for tighter evaluations of dynamic resource allocation algorithms.

2 - A Trajectory-Based and Data-Light Approach to Predicting Flight Time of Arrival
Bo Zou, Zhe Zheng, Wenbin Wei

This paper proposes a novel, trajectory-based, and data-light approach to predict estimated time of arrival (ETA) at terminal airspace boundary (ETA_TAB) and ETA at destination runway (i.e., estimated landing time, or ELDT) for flights at any point en route. Rather than requiring a large amount of data encompassing detailed flight position recordings, aircraft aerodynamics, weather conditions while a flight is en route, this approach only needs flight trajectory information that can be relatively easily accessed. The approach consists of four steps. First, for the flight under study, the trajectory that has been flown is compared with trajectories of historic flights to determine the best matched historic trajectory. Using the best matched trajectory, in the second step a refined long short-term (LSTM) memory neural network model is trained and then used to predict the remaining trajectory of the flight under study. As LSTM training using a historic trajectory can be done off-line, this step of trajectory prediction can be performed in real time. Third, to predict time of arrival speed information is needed. A gradient boosting machine model is trained to sequentially predict flight ground speed. Lastly, the predicted trajectory and speed are used to compute ETA_TAB and ELDT. We apply this approach to a number of flights flying between two airport pairs in the US. Results show superior performance of the approach over alternative methods.

3 - A column generation based hyper-heuristic algorithm for solving the aircraft recovery problem
David Torres Sanchez, Burak Boyaci, Konstantinos G. Zografos

In this work, we develop a new hybrid solution procedure to solve the aircraft recovery problem. We propose a framework that generates flight schedules to minimize costs associated with flight cancellations and delays while adheringto the operational constraints imposed by the regulations. The hybrid solution procedure uses a column generation based algorithm leading to formulation of Shortest Path Problems with Resource Constraints (SPPRC). To efficiently solve the resulting intractable SPPRCs, we developed a column generation based hyper-heuristic algorithm that selects exact and heuristic methods in the column generation procedure based on their historical performance. In addition, we improved the exact method to solve SPPRCs by developing a bidirectional labelling algorithm with dynamic halfway points and restricted dominance relations. Since the labelling algorithm is the bottleneck of our approach, these improvements led to a significant solution time reduction. Finally, yet importantly, to find not only tight lower bounds but also good feasible solutions to the aircraft recovery problem, we utilize a diving heuristic with the column generation procedure. The proposed framework managed to solve instances of practical size in a reasonable time.

■ TE-52

Tuesday, 16:30-18:00 - Virtual Room 52

Addressing Uncertainty in Climate Policy

Stream: OR in Climate Policy and Planning
Invited session
Chair: *Alexandros Nikas*
Chair: *Haris Doukas*

1 - Interlinking climate action and sustainable development: a fuzzy linguistic group decision making framework
Anastasios Karamaneas, Lorenza Campagnolo, Konstantinos Koasidis, Michael Saulo, Ioannis Tsipouridis, Ajay Gambhir, Dirk-Jan Van de Ven, Zsolt Lengyel, Ben McWilliams, Alexandros Nikas, Haris Doukas

The Paris Agreement and the 2030 Agenda for Sustainable Development embody highly intertwined targets and guidelines to act for the climate crisis in conjunction with sustainability. Interlinking climate action and sustainable development is key to prioritising research and informing future mitigation analysis and policy. Here we seek to establish a methodology for implicitly eliciting stakeholders' unbiased preferences, based on a fuzzy linguistic group decision making and consensus framework. Two separate individual multicriteria analysis exercises are carried out: climate action and sustainability dimensions are decision alternatives and evaluation criteria respectively in the first exercise, and vice versa in the second. The two exercises are coupled in a feedback process, allowing modification of criteria weights to reduce bias and therefore uncertainty. The analysis, as part of the PARIS REINFORCE project (GA: 820846), is performed using the 2-tuple group TOPSIS model, coupled with a consensus measuring method to provide robust and widely accepted preferences expressed in a linguistic form that is closer to the natural language of the stakeholders. The proposed framework is validated in a case study aiming to prioritise action for Sustainable Development Goals and sectoral decarbonisation in Kenya, with results pinpointing a clear strategy for mitigation analysis, and indicating an increase in consensus of the group priorities in the interlinked framework.

2 - A multiple-criteria evaluation framework for seaport sustainability considering non-homogeneous variables and uncertainty: the case of Piraeus, Greece
Eleni Kanellou, Konstantinos Koasidis, Vasiliki Daniil, Alexandros Nikas, John Psarras

The maritime industry is associated with high amounts of emissions produced. With shipping being excluded from the Paris Agreement, the International Maritime Organization has set a 50% CO2 emissions reduction target, although, a concrete pathway has yet to be established, with negotiations being in progress to set a roadmap for the sector after 2023. Seaports are critical in the sector's sustainability. Infrastructural interventions not only reduce direct emissions from ports, but also enable the use of a more efficient fleet. Here, we attempt to contribute to the development of the roadmap, as part of the PARIS REINFORCE research project, by establishing a multi-criteria assessment framework to assess the implementation of different interventions in ports, coupled with sensitivity analysis to increase robustness. Evaluation criteria of the study include environmental benefits, economic viability, capacity to implement and time frame of implementation. Uncertainty is considered in two routes: first, heterogeneous variables are introduced to embed stakeholder knowledge and aggregated in the model towards capturing the spectrum of assessments without loss of information; second, sensitivity analyses for perturbations over input parameters are carried out to evaluate impacts of perturbations on the final rankings. The proposed framework is validated in a case study for the port of Piraeus, including a wide range of readily available technologies proposed in the literature.

3 - Exploring the impact of analyst's choices in fuzzy cognitive maps for climate policy applications
Themistoklis Koutsellis, Konstantinos Koasidis, Alexandros Nikas, Haris Doukas

Fuzzy Cognitive Maps (FCMs) have recently gained ground in energy and climate policy applications, partly due to stakeholders encountering difficulties in understanding, or being excluded from, state-of-the-art policy support frameworks, like energy- and climate-economic modelling tools. Due to limited model complexity and reliance on quantitative data, FCMs have proliferated as a decision support tool at the local level, allowing policymakers to reflect their understanding of a problem domain in a structured manner and act based on it. They have also been proposed as an effective way to bridge the science-policy gap and engage stakeholders in modelling processes. The simplicity and attractiveness of FCMs lies in their ability to capture the perception of a system in graphical representations consisting of concepts (nodes) and interconnections (weights) among these nodes, which are characterised by activation functions determining the state vector of the system in simulation, while their values are controlled via transfer functions. The topology of nodes, weights, activation and transfer functions, however, are formulated differently: the former are defined by stakeholders, but the latter are selected by the analysts. In essence, like stakeholders, the analysts are required to take decisions, which are both relevant to the analysis and critical to its results. Here, we explore the effect of these scientific choices on the resulting policy prescriptions.

4 - Identifying optimal COVID-19 recovery packages: a robust IAM-portfolio analysis of renewable energy technological subsidisation
Alexandros Nikas, Aikaterini Forouli, Dirk-Jan Van de Ven, Konstantinos Koasidis, Ajay Gambhir, Themistoklis Koutsellis, Haris Doukas

The pandemic has had significant impacts on the European economy, with approximately 1.8 million EU citizens losing their jobs between September 2019 and September 2020. Towards facilitating a swift and sustainable recovery, the EU launched the Recovery and Resilience Facility (RRF) to provide EUR 672.5 billion of financial support to Member States in the coming years. In line with the European Green Deal and climate efforts, 37% of investments in national plans requesting RRF financing must focus on a "green" transition. Here we seek the optimal allocation of renewable energy subsidies from the EU COVID-19 recovery package. Towards further mitigating emissions and creating new jobs in the transition, on top of a current EU policy scenario, as part of the PARIS REINFORCE project (GA: 820846), we use budgets aligned with announced plans at the Community level, and couple integrated assessment modelling with portfolio analysis. We use the Global Change Assessment Model (GCAM), to explore where the European energy system and emissions are headed given current climate policy in the Union; and employ the robust augmented ϵ-constraint (AUGMECON-R) model with Monte Carlo simulations to identify optimal power generation technological subsidy portfolios and assess their robustness against stochastic uncertainty of input parameters.

■ TE-53

Tuesday, 16:30-18:00 - Virtual Room 53

Software for (MI)NLP

Stream: Software for Optimization
Invited session
Chair: *Robert Fourer*

1 - A Pyomo-based Solver for Robust Optimization with Nonconvex Models
Chrysanthos E. Gounaris, Natalie Isenberg, John Siirola

Despite the tremendous advances in the area of Robust Optimization (RO) for linear or convex models, which lend themselves to duality-based solution methodologies and tractability guarantees, there is an important gap in our ability to reliably identify robust solutions to nonconvex models. Whereas solving such models is often challenging even in a deterministic setting, there exists a pressing need to solve them while accounting for the effects parametric uncertainty that they are subject to. Such uncertainty often exists in the form of epistemic uncertainty, market variability, and/or fluctuations of the boundary conditions in which the designed system will be called to operate over long future horizons. In this talk, we highlight the methodological challenges associated with applying RO principles in the context of nonconvex models. We then present our recent development of a generalized cutting set algorithm and its associated implementation in the Pyomo modeling language. Our implementation can efficiently identify robust solutions to nonconvex models under a multitude of uncertainty characterizations, including both continuous and discrete uncertainty sets. Using various forms of decision rules, including nonlinear forms, our algorithm is shown to be able to solve nonconvex RO models in a two-stage setting, supporting also the design-and-operate and/or the plan-and-schedule settings.

2 - A2DR: Open-Source Python Solver for Prox-Affine Distributed Convex Optimization
Junzi Zhang, Anqi Fu, Stephen Boyd

We consider the problem of finite-sum non-smooth convex optimization with general linear constraints, where the objective function summands are only accessible through their proximal operators. To solve it, we propose an Anderson accelerated Douglas-Rachford splitting (A2DR) algorithm, which combines the scalability of Douglas-Rachford splitting and the fast convergence of Anderson acceleration. We show that A2DR either globally converges or provides a certificate of infeasibility/unboundedness under very mild conditions. We describe an open-source implementation (https://github.com/cvxgrp/a2dr) and demonstrate its outstanding performance on a wide range of examples. The talk is mainly based on the joint work [SIAM Journal on Scientific Computing, 42.6 (2020): A3560-A3583] with Anqi Fu and Stephen Boyd.

3 - Robust conic optimization in Python
Maximilian Stahlberg

The Python ecosystem, despite being a leading programming environment for scientific computing and rapid prototyping that offers multiple mathematical optimization frameworks to choose from, has so far provided little support for solving robust and distributionally robust optimization models. To address this, we present an extension of the Python-embedded optimization modeling language PICOS that covers key results from both fields and provides a platform for the implementation of additional models where the robust counterpart of a problem has a conic representation. We start the talk with a brief introduction to the modeling interface provided by PICOS, then we discuss some of its new features concerned with optimization under uncertainty. In particular, we present an illustrative application in linear signal estimation where Wasserstein-robust stochastic programming yields a significantly lower generalization error than L2-regularized least squares regression.

4 - PreProcessing Nonlinear Programs to Make Them Easier to Solve
Linus Schrage

We describe features added to LINDO software to preprocess nonlinear optimization models to make them easier to find proven global optima. These features fall under the general categories: exploiting single variable constraints, identifying and exploiting convex expressions, linearizing susceptible nonlinear functions, identifying and exploiting common terms, and identifying which variables should be branching variables.

■ TE-55

Tuesday, 16:30-18:00 - Virtual Room 55

Optimization Models for Machine Learning

Stream: EURO Working Group Data Science meets Optimisation
Invited session
Chair: *Dimitri Papadimitriou*

1 - Optimal demand response scheduling of a residential Microgrid with consideration of prosumer preferences
Mohamed Saâd El Harrab, Michel Nakhla

The electrical system must handle increasing production from renewable sources that are difficult to predict, highly variable and not controllable. This shift in the electrical paradigm makes power grid operation, and therefore the exercise of supply/demand balance, increasingly complex. Microgrids (MG) enable a more flexible management of the grid. These intelligent bidirectional systems allow to reach new sources of flexibility from consumers using Demand Response (DR). Based on Stochastic Optimization and Deep Learning approaches, we propose an optimal demand response scheduling under load uncertainty in a residential MG. For each household in the MG, we perform clustering in order to identify transferable loads and forecast these loads to evaluate the micro-flexibilities potential. Then optimal schedule strategy is obtained by maximizing the MG operator's DR payoff while satisfying the load demand and user's comfort constraints. Simulation results show that the proposed DR scheduling is beneficial to both service provider's and prosumer.

2 - Classification Rules for Interpretable Learning with Linear Programming
M.Hakan Akyuz, Ilker Birbil

Rules are a set of if-then statements which contain one or more conditions to classify a subset of samples in a dataset. Such classification rules are considered to be interpretable by the decision makers in many applications. This work introduces two new algorithms for interpretable learning. Both algorithms take advantage of linear programming which makes them scalable to large data sets. The first algorithm extracts rules for interpretation of black-box methods that are based on tree/rule ensembles. The second algorithm generates a set of classification rules using a column generation approach. The suggested algorithms return a set of rules along with their optimal weights indicating the importance of each rule for classification. Moreover, our algorithms allow assigning cost coefficients, which could relate to different attributes of the rules, such as; rule lengths, estimator weights, number of false negatives, and so on. Thus, the decision makers can get involved in the training process by changing these coefficients and obtain alternative set of rules that are more convenient for their needs. We have tested the performance of both algorithms on a collection of standard datasets. Our algorithms are promising and achieve a good compromise between interpretability and accuracy.

3 - Genetic algorithm with penalty function for detecting and assignment of unexpected tasks in embedded systems design process
Adam Górski, Maciej Ogorzałek

Embedded system is microprocessor based computer system programmed to execute appropriate tasks. Meanwhile large group are distributed architectures the tasks can be executed parallelly. Most of embedded systems designing approaches work with constant number of tasks. The real problem appears when some unexpected task must be executed. In such situations the design process, or its part, need to be repeated. To solve that problem some algorithms for assignment and detecting of unexpected tasks were proposed. Most of them are evolutionary algorithms. However one of the biggest disadvantages of those solutions is that they can only evolved valid solutions which do not exceed time limits. Thus it is a chance that the algorithms can stop in local minima of optimizing parameters. Therefore we present a genetic algorithms based approach for detecting and assignment of unexpected tasks in embedded systems design process which uses a penalty function during evolution. Unlike existing methods our algorithm evolves every obtained individuals. During the evolution the individuals which exceed the limitations are given a penalty proportioned to the violation time. Such an approach can improve the quality of the results by helping the algorithm to escape from local minima of optimizing parameters.

4 - Finding descent directions for non-linear composite problems and applications
Dimitri Papadimitriou, Cong Bang Vu

This work exploits the duality frameworks in convex optimization for finding descent directions for non-linear composite problems. We use a simple procedure based on the Fenchel-Rockafellar duality for finding a descent direction. Then, invoking this procedure into the line search methods yields efficient methods for non-linear composite problems. The resulting algorithm brings a powerful combination of the Prox-Linear, the Dual Fast Iterative Shrinkage/Tresholding Algorithm (FISTA) and the weak Wolfe line search as illustrated by numerical results

■ TE-56

Tuesday, 16:30-18:00 - Virtual Room 56

Last minute changes 5

Stream: Last minute changes
Invited session
Chair: *Mahsa Alirezaei*

1 - Scenarios of Profitability and Employment in Western Mediterranean Demersal Fisheries in Effort Control Regime
Negar Akbari

Mediterranean fisheries show clear signs of overexploitation of the main fish stocks, modifications to marine ecosystems and low economic performance. The purpose of this study is to compare scenarios based on effort limitation to assess under which conditions economic yield could be maximised in Western Mediterranean demersal fisheries. In this study a modelling approach based on three steps is pursued as following: i) a bioeconomic model is applied for projecting the expected landings of the target species in the case study region, ii) an optimisation model is adopted that determines the maximum profitability while maintaining a balance between employment, fuel price and predefined catch levels, iii) a multiple scenario analysis is adopted to model the different permutations of input parameters (i.e., fuel price, fish price and crew cost) and to compare and contrast the results. The outcomes of this study will enhance the understanding of the long- and short-term impacts of effort limitations and climate change scenarios, and which policy measures are better suited to balance the conflicting goals of maintaining a sustainable level of profitability, catch levels and employment in the Mediterranean fisheries.

2 - A collaborative approach for supporting wine grape harvesting planning
Franco Basso, Mauricio Varas, Raul Pezoa, Paul Bosch, Juan Pablo Contreras

Horizontal collaboration is a cooperative strategy that has increasingly been used for improving supply chain members' performance. In this paper, we analyze the benefits of using a collaborative approach for wine grape harvesting. We assess how joint planning of labor and machinery capacity impacts harvesting costs. We consider four hiring policies that allow us to analyze the benefits of collaboration in the most restrictive case and compare it with the most flexible case, in which coalitions can both hire/rent and hire/return multiple times. We model cooperation among wineries as a coalitional game with transferable costs. In this case, the characteristic function vector is derived from a mixed-integer programming formulation. We review two coalition structures and cost allocation models developed elsewhere: the equal profit method and the entropy method, and we devise a new approach that uses the Gini index as a driver for cost-splitting. We perform several numerical experiments considering a harvesting instance gathered from the literature. Our results show that the fairness criteria used significantly impact both the coalitions formed and the sharing of costs for the wine grape harvesting process. In particular, the Gini method favors the formation of smaller coalitions. Besides, the entropy method's solutions show a more equitable behavior when evaluated on the other two fairness criteria.

3 - Considering the role of personality in the impact of emphasis on safety and productivity in warehouse driving: A VR experiment
Mahsa Alirezaei, Jelle de Vries, René de Koster

Balancing the often-competing goals of productivity and safety is an ongoing challenge in Operations Management in general, and in warehouses specifically. Employees are often pushed to work faster to meet increasingly tight delivery deadlines, while accident risks are omnipresent. Organizations may emphasize safe and productive work through various instructions. However, the combined impact of emphasis on speed, quality, and safety remains unclear in operations management and warehousing. This study employs controlled laboratory experiments involving a Virtual Reality (VR) simulator to examine the impact of audio reminders on the performance of warehouse vehicle drivers. The VR technology makes it possible to offer a realistic and fully immersive experience to the participants, while not exposing them to real safety risks. Drawing on concepts from productivity-safety tradeoffs, we study three types of audio reminders by emphasizing time pressure, safety, and safety combined with time pressure. More importantly, it is likely that workers with different types of personalities will be affected differently by the audio reminders. We therefore also measure individual differences between drivers; in terms of the Big five personality traits and Regulatory Focus. This experiment is designed in a 2*2 factorial design, in which the safety-related audio is considered as a within-subject manipulation and the productivity-related audio is considered as a between-subject manipulation.

4 - Introducing Panocracy: and People-Driven Governance
Cathal MacSwiney Brugha

Two opposite drivers of governance are resource-driven and people-driven. With resource-driven, subjectors, whether corporate or autocratic, subject and obtain resources for their own ends. Then agencies, whether educational or democratic, project and develop what subjectors have obtained. Next institutions, whether state or bureaucratic, connect and advance what agencies have developed: hospitals, schools, housing, industry. The intention, then, is that communities, whether voluntary or panocratic, would reflect and integrate what institutions have advanced, to benefit the people. Except this doesn't happen. There is no panocracy, no reflecting governance of, by, and for all the people. The alternative people-driven governance starts with communities, whether voluntary or panocratic, that reflect people's intentions and integrates them into systems. Then institutions, whether state or bureaucratic, connect and advance what communities have integrated. Next agencies, whether educational or democratic, project and develop what institutions have advanced. Finally, subjectors, whether corporate or autocratic, subject and obtain the resources needed for what the agencies have developed. Except none of this happens. Resource-driven governance by autocrats and bureaucrats has depleted the planet's air, energy, environment, cannot cope with pandemics. People-driven governance needs both democrats and panocrats, and we governance analytics experts should develop this future.

■ TE-57

Tuesday, 16:30-18:00 - Virtual Room 57

Heuristics and matheuristics

Stream: Heuristic Optimization
Invited session
Chair: *Yun Lu*

1 - Methodology for Generating Bounded Solutions for the Set K-Covering Problems
Yun Lu, Francis Vasko

In this talk, we will present a simple methodology that iteratively solves COPs using CPLEX to generate solutions that are within a tight tolerance of the optimums, but require a reasonable amount of computer time. This robust procedure allows the user to specify two sequences of tolerance and maximum execution time. We will apply this methodology to solve 135 set K-covering problems (SKCP) commonly used by researchers to test the performance of metaheuristics for the SKCP.

2 - A Discrete Event Multi-Agent Based Approach to the Scheduling and Routing Problems in a RMFS.
Sander Teck, Reginald Dewil

This paper provides a Discrete Event Multi-Agent (DE-MAS) based approach for solving the scheduling and routing of robots and pickers in a Robotic Mobile Fulfillment System (RMFS). The RMFS is a parts-to-picker system designed for e-commerce warehousing where robots are used to fetch inventory pods from the storage area and transport them to the appropriate workstation where human pickers pick the required number of SKUs for the orders assigned to their work station. It is composed of several hard sub problems like: the order-to-workstation scheduling, the pod selection, the vehicle scheduling, and several more. The proposed solution approach employs negotiation mechanisms, i.e. auctions, to communicate and distribute the tasks among all the agents. The DE-MAS is compared with a centralized optimization algorithm and (greedy) dispatching rules and is tested on a wide set of problem instances of the RMFS with varying numbers of AGVs, workstations, and order sizes. The DE-MAS shows promising results compared to the central algorithm, requiring only a fraction of the computation time and it outperforms the dispatching rules found in literature. In addition, a comparison in optimization potential is made between uni-directional and bi-directional lanes, where for bi-directional lanes a collision resolution algorithm is implemented.

3 - Solving the Capacitated Location-Routing Problem via an Iterative Matheuristic Algorithm
Theocharis Metzidakis, Panagiotis Repoussis, Manolis Kritikos, George Ioannou

This work presents a matheuristic algorithm for the so-called Capacitated Location Routing Problem (CLRP). The CLRP is a well-know, hard to solve optimization problem that can be found in various real-life settings. Let a set of candidate depot locations and a set of geographically scattered customers with known demands. The aim is to locate facilities and design least cost vehicle routes to service the customers using a fixed fleet of homogeneous capacitated vehicles. The objective is to minimize the total cost subject to capacity and other constraints. An iterative two-phase algorithmic framework is employed that alternates between depot location and vehicle routing phases, respectively. In the first phase, a facility location problem is solved exactly. Based on the location of facilities and the assignment of customers to depots a candidate solution is generated via a greedy heuristic algorithm. In the second phase, the candidate solution is used to generate partially fixed multi-depot vehicle routing sub-problems. These sub-problems are optimally solved via an exact branch-and-cut MIP approach. The best solution found is recorded, and the overall scheme is repeated. The previous customer assignment to depots is restricted. Based on benchmark datasets taken from the literature, various computational results are reported.

4 - Metaheuristic Approaches for Generalized Assignment Problem of An Online Education Website
Merve Özer

BinYaprak is a TurkishWIN (Turkish Women's International Network) initiative that offers role model stories for inspiration, educational content, and real-life stories as well as a networking platform through online and offline events. BinYaprak online education website aims to create ways for content and network aggregation between experts and learners for the ease of knowledge discovery. Experts are the people who join the platform for free in order to share their knowledge and experience with interested learners. Learners join the platform for free to learn new skills, access new networks, and find out about new jobs and opportunities. Thus, this study aims to provide an assignment of a learner to an expert which satisfies both sides as much as possible. An expert may be assigned to multiple learners ensuring each learner is assigned at most one expert, thus the problem becomes a generalized assignment (GAP) which is known to be NP-Hard. In this study, we present an implementation of a new nature-inspired metaheuristic algorithm called Migrating Birds Optimization (MBO) and a hybrid Simulated Annealing and Tabu Search method to solve the GAP of BinYaprak online education website. In our computational study, we solve a set of small and large instances of GAP by using Gurobi Python API to use it as a baseline reference against which we can compare our heuristic methods. Our numerical analyzes show that the hybrid SA/TS performs better on GAP.

■ TE-58

Tuesday, 16:30-18:00 - Virtual Room 58

Optimization for Cancer Treatment

Stream: ORAHS: OR in Health and Healthcare
Invited session
Chair: *Joana Matos Dias*
Chair: *Humberto Rocha*

1 - Discrete-event simulation for radiotherapy centre management in the COVID-19 pandemic
Ralf Müller-Polyzou, Melanie Reuter-Oppermann, Elisabeth Jambor

Radiotherapy is an important modality for modern cancer treatment. The optimisation of business processes is important for the safe and effective radiotherapy treatment, while maintaining economic efficiency. To reach this goal, patient admission, CT and MRI imaging, radiotherapy planning and delivery, and after-care processes must be well coordinated. Our research project aims at developing a combined discreet-event and agent-based simulation of a generic radiotherapy centre. Modeling and simulation requirements are elaborated in a structured literature research and selected expert interviews. Furthermore, radiotherapy processes documented in the literature are used for simulation modelling. Data needed for the simulation is collected from real-world radiotherapy centres. The implementation in the simulation software AnyLogic is checked for plausibility with medical physics experts. The simulation will be used to analyse a set of scenarios for COVID-19 protection measures widely implemented in radiotherapy centres worldwide considering patient throughput, waiting times and resource utilisation.

2 - Local search movements for the direct aperture optimisation problem
Mauricio Moyano, Guillermo Cabrera-Guerrero, Carolina Lagos

Radiotherapy is a cancer treatment that uses high doses of radiation to destroy cancerous cells and shrink tumours while sparing surrounding organs at risk (OARs). one of the most common techniques within radiotherapy is Intensity Modulated Radiation Therapy (IMRT). When IMRT is approached as a sequential problem, we first need to establish a set of beam angles from which radiation will be delivered from. Then, the radiation intensities for each selected beam angles are computed. Finally, the sequence of apertures we need to deliver the computed treatment plan is generated. Unlike this sequential approach, in the Direct Aperture Optimisation (DAO) problems, constraints associated with the number of deliverable aperture shapes, along with machines' physical constraints, are taken into consideration while the intensities optimisation process is taking place. DAO approach, in general, generates better treatments with fewer apertures for IMRT. In this work, we propose new local search movements to efficiently solve the DAO problem. We apply our algorithm to a prostate cancer case to compare the movements.

3 - Selection of beam directions for prostate cancer treated with intensity-modulated proton therapy using a randomized direct-search method
Humberto Rocha, Joana Matos Dias

The ultimate goal of a radiotherapy treatment plan would be to irradiate the tumor volume with 100% of the prescribed dose while the surrounding organs and tissues would not receive any dose at all. Although this perfect balance is (still) impossible and a clinically acceptable plan has to consider multiple trade-offs, proton therapy has brought us closer to that goal due to the unique depth-dose characteristics of protons: dose is slowly deposited along the beam path before reaching a sharp peak, known as the Bragg peak, rapidly falling to almost zero beyond the peak. To ensure a highly conformal dose in the tumor while sparing the surrounding structures requires the optimization of different parameters including the optimal selection of beam directions. For prostate cancer cases, appropriate beam selection is even more critical as proton therapy typically uses only a couple of beams. In this study, we propose a randomized direct-search method for beam angle optimization for prostate cancer treated with intensity-modulated proton therapy. Compared to deterministic directional direct-search methods, successfully used in conventional radiotherapy for beam angle selection, the randomized approach obtained comparable results but in a faster computational time.

4 - Clinical validation of a graphical method for radiation therapy plan quality assessment: elicitation of preferences using linear programming
Joana Matos Dias, Humberto Rocha, Tiago Ventura, Maria do Carmo Lopes, Brígida da Costa Ferreira

The delivery of radiotherapy is based on a personalized dose plan aiming at simultaneously irradiating the target with the prescription dose and causing little or no damage to the organs-at-risk (OAR). There are trade-offs between the dose delivered to the targets and to the normal tissues. The clinical assessment of plan quality is done by inspecting the isodoses displayed on top of the computed tomography images and evaluating dose-volume histograms and the corresponding dose statistics. If two or more of the best plans are to be compared, the assessment task becomes extremely demanding. As a result, plan selection is based on the information that the radiation oncologist (RO) managed to hold or considered more relevant which may lead to unsystematic and/or subjective decisions. Recently, a graphical method, SPIDERplan, was developed to assess and compare the quality of radiation therapy plans. It considers the clinical aims associated with each of the structures of interest weighting their relative importance. SPIDERplan was applied for plan selection considering nasopharynx cancer cases. In the first phase of the study, pairs of plans were blindly and independently evaluated by three ROs. Then, the weights' configuration of SPIDERplan was automatically performed using a mixed linear programming model for preference elicitation. It was possible to conclude that SPIDERplan evaluation with automatic weight elicitation agreed with most of the ROs assessments.

■ TE-59

Tuesday, 16:30-18:00 - Virtual Room 59

OR for Development and Emerging or Developing Countries

Stream: OR for Development, Developing Countries and Sustainable Development
Invited session
Chair: *Olabode Adewoye*
Chair: *Elise del Rosario*

1 - Insight into the Implementation of Sustainable Construction Project Management: A Comparative Analysis of the UK and Iraq
Mohammed Mustafa Hasan Alyasiri, Karim Ahmed

The construction industry is among the most important, accounting for 10% of GDP and providing at least 7% of jobs worldwide (Djokoto, Dadzie and Ohemeng-Ababio 2014), but it also consumes about 40% of all energy generated, 40% of raw materials, while generating about 35-40% of CO2 emissions and 30-40% of all solid waste. There is, therefore, a strong impetus for construction to be conducted more sustainably, and this is particularly important in developing economies that are seeing a rapid expansion in construction, but which are currently often poorly equipped to manage sustainable construction projects. It is in this context that this study seeks to identify the most significant drivers and barriers affecting the implementation of sustainable construction projects in Iraq, comparing these to the situation in the UK. Data is gathered from the literature and an online questionnaire of relevant professionals in Iraq.The findings indicate that the main barriers to implementing sustainable construction projects in Iraq are the high cost, lack of clients' awareness, and lack of government support. The most important drivers, meanwhile, were raising stakeholders' awareness, providing financial incentives, and positing legislations and rules. Based on the comparison with the UK situation, which identified many similar concerns, albeit, with different rankings, a number of recommendations were made to support sustainable construction in Iraq.

2 - Africa Transcontinental Railway routes planning by using statistical analytics tool in Phase North Africa to West Africa
Chi-Feng Ho, Chi-hong Ho

The overall economy in Africa was in a downward trend since 2016, which had been affected by the oil price reductions. Because of increasing the amount of exploited Shale Oil, the oil price decreased which affected African countries' economy hugely. Most of the countries in Africa are not developing as well, which have lots of natural resources underground, but they did not have the economic capability to exploit. The authors proposed that building transcontinental railways could increase employment opportunities and improve the economic condition of crossing areas. Based on the Economy, Natural Resource and Tourism data of each country, the author used a clustering method to see the similarity of the total of 23 countries. Z-Transformations are used to validate eligible GDP/GNI in each country for our consideration and using robust fit outlier detection to determine countries' economy is below or above the average. The natural resources are not easy to find the real data, authors use text mining tools to filter out how many natural resources one country has and do the comparison. The weighted value established a fair-platform to consider whether to cross the country or not. The authors decided only to think above [U+2154] value of the highest weighted country. Lastly, the authors both agreed not to connect the railway with the countries during the war period, because the public construction will be destroyed first.

3 - A look at the convergence of the WHO Member States regarding the UN's SDG 3
Miguel Pereira, Ana Camanho, Rui Marques, José Rui Figueira

The study of convergence in productivity concerns whether entities in a given industry get closer to the best practices or not, and whether the gap between the best and worst practice frontiers (BPF and WPF) decreases over time. In a multi-input multi-output setting, the assessment of sigma- and beta-convergence can be measured by non-parametric frontier techniques, such as data envelopment analysis. Here, we propose an innovative approach to estimate convergence in the context of performance assessments resting on composite indicators, taking desirable and undesirable indicators into account. This methodology relies on 'Benefit-of-the-Doubt' models, specified with a directional distance function. It is applied to the Member States of the World Health Organization (WHO), in order to study their convergence in terms of the United Nations' Sustainable Development Goal (SDG) 'Good health and well-being'. Data covering the period 2016-2020 was collected, since it concerns all years since the proposal of the SDGs. In the end, the results show that the Eastern Mediterranean Region, the European Region, and the Region of the Americas are sigma- and beta-convergent. Nonetheless, the WHO Member States in the South-East Asia Region are departing from the BPF and increasing the gap between the BPF and the WPF. Worldwide, most WHO Member States have been able to close the gap between BPFs and WPFs by improving the WPF, even though it occurred alongside a decline in the BPF.

4 - Impact of COVID-19 on Higher Education in Nigeria
Olabode Adewoye

The outbreak of coronavirus termed COVID -19 world-wide which started in late 2019 in Wuhan, China and was declared pandemic in March 2020 by the World Health Organisation (WHO) has disrupted every aspect of human life. The educational sector, just like every other sectors has been greatly affected. We now have what we called the "New Normal". The first case of COVID -19 in Nigeria was recorded in February 27, 2020 and has attracted government attention aimed at reducing the spread of COVID - 19. As part of the measures to curb the spread of the virus all educational institutions in Nigeria were closed down. Lagos State and the Federal Capital Territory, Abuja were completely locked down out the 36 states in Nigeria. The remaining states were partially locked down. Despite the locked down and total closure of schools in Nigeria, learning continues via online methods. This work attempt to provide a better understanding of how covid-19 has affected educational system in Nigeria. Survey was conducted and using the available data, statistical tools were used to analyse the relationship between attendance of online classes and students examination scores. Finding shows that many students suffered learning loss and which negatively impact students' performance. Result also indicates that COVID -19 affect students differently.

■ TE-60

Tuesday, 16:30-18:00 - Virtual Room 60

Cutting and packing applications I

Stream: Cutting and Packing
Invited session
Chair: *Maria Teresa Alonso Martínez*

1 - The pallet-packing split delivery vehicle routing problem with stability and axle-weight constraints
Iván Giménez-Palacios, Maria Teresa Alonso Martínez, Ramon Alvarez-Valdes, Francisco Parreño

Today, logistics is becoming increasingly important with the rise of e-commerce companies. For these companies, it is interesting to know in advance the minimum number of trucks they will need to cover their demand, and thus be able to make decisions about the size of their fleet. The pallet-packing split delivery vehicle routing problem consists of obtaining a set of routes, minimising the distance travelled, to cover the entire demand, considering hard packing constraints such as axle weight and load stability. In this case, the demand is composed of pallets, each with a different weight. In addition, we allow splitting a customer's load into two or more different trucks, even if this load fits completely on a single truck. We propose an integer model and a matheuristic algorithm to determine the minimum number of trucks needed for a given instance of the problem. To test these procedures, we have generated a set of instances varying pallet weights, demand size, and number of customers.

2 - A two-step heuristic procedure for the two-dimensional cutting stock problem with usable leftovers
Douglas Nogueira do Nascimento, Adriana Cherri, José Fernando Oliveira

In this work, we deal with the Two-Dimensional Cutting Stock Problem with Usable Leftovers (2D-CSPUL) which has great practical importance for multiple industries, due to the reduction in the waste of raw materials. If well planned, usable leftovers can be generated with a high probability of use in future cutting processes, providing a substantial economic and environmental impact. We propose a two-step heuristic procedure to solve the 2D-CSPUL. In the first step, this procedure generates a set of cutting patterns for all types of plates in stock. Then, in the second step, it solves iteratively a mathematical model that defines the frequency of each cutting pattern created in the previous step. At each iteration, the model allows the creation of one new cutting pattern that will be available for the next iterations. Computational experiments were performed with instances from the literature and instances generated with a problem generator. The obtained results were satisfactory. This research has been supported by the Fundação de Amparo a Pesquisa do Estado de São Paulo - FAPESP [2018/16600-0], [2018/07240-0] and [2016/01860-1]. This work is also partially funded by the ERDF - European Regional Development Fund through the Operational Programme for Competitiveness and Internationalisation - COMPETE 2020 Programme and by National Funds through the Portuguese funding agency, FCT - Fundação para a Ciência e a Tecnologia, I.P., within project POCI-01-0145-FEDER-029609.

3 - The pallet-loading vehicle routing problem with stability constraints
Maria Teresa Alonso Martínez, Ramon Alvarez-Valdes, Francisco Parreño, Antonio Martinez-sykora

We will present our mathematical model and results for a distribution problem that includes both the packing and routing of customer orders. The model needs to assign pallets to trucks, decide the position of the pallets on the trucks so that a customer's pallets are together and finally the route the trucks will take. A has to decide how to load the products into trucks and determine the route of each truck. The demand of a customer can exceed the truck capacity and, therefore, we allow solutions that split the delivery of a given customer across several trucks. Each truck can carry a maximum weight each axle. In addition, the load inside each truck must be stable. All these routing and packing constraints are included into an integer linear model where the objective is to minimize the total travel distance.We present an extensive computational study, varying the number and locations of the customers and the number and weight of the demanded pallets, which shows the performance and the limits of the proposed model. Since the model becomes intractable with even small instances, we propose a decomposition algorithm in which some of the packing constraints are relaxed in the model and then considered by a heuristic packing algorithm. If the heuristic fails, an auxiliary model is then used to ensure the optimality of the solution obtained.

■ TE-61

Tuesday, 16:30-18:00 - Virtual Room 61

Queues with Strategic Customers I

Stream: Queues with Strategic Customers
Invited session
Chair: *Antonis Economou*
Chair: *Olga Bountali*
Chair: *Athanasia Manou*

1 - Increasing Social Welfare with Delays: Strategic Customers in the M/G/1 Orbit Queue
Athanasia Manou, Opher Baron, Antonis Economou

In most cases the equilibrium behavior of utility maximizing customers in queues results in a usage rate that is higher than the welfare-maximizing usage rate. Therefore, much of the literature has been dedicated to finding queueing control policies that could coordinate the system, i.e., induce the customers to join at a rate that maximizes the social welfare. The literature studied this issue in the context of work-conserving policies. However, recent literature demonstrates that idling servers may have positive impact on the operation of some queueing systems. These facts bring up the question of "could a non-work-conserving service discipline improve the social welfare of a system with strategic customers (or even coordinate it)?".

In this work we consider this question and demonstrate that, under some circumstances, the answer is positive. Because in practice it is socially optimal for customers who face an idle server to join, delaying only waiting customers is an intuitively appealing method to introduce delay that would maximize the social welfare. Therefore, we focus our study on the M/G/1 queue with orbit. This queueing model with a non-work-conserving discipline imposes additional delays (retrieving times) on queued customers. We characterize customer equilibrium behavior in this system under two levels of information, and demonstrate how the delays can improve the welfare generated by the system.

2 - Strategic Customers with Correlated Preferences
Zeynep Gökçe İşlier, Refik Gullu

Service systems are generally queuing type systems because there are a limited number of service providers but many customers. Therefore, many service systems include queues that bring the displeasure of waiting in the queue for customers. In addition to different waiting sensitivities, the service valuations of customers for an enhanced service are also different. Because both waiting sensitivity and service evaluations differ among customers, priority service can be offered by the service provider. In our study, we model a single server service system and analyse the premium service price that maximizes the priority revenue for the service provider by regarding customers' decisions to purchase a premium service. We first consider customers with constant waiting cost and service valuation. Then, we consider customers with their unique waiting cost and service valuation. Moreover, it is assumed that the relationship between the waiting cost and service valuation can be different for each customer. Therefore, we study how the correlation between customers' waiting sensitivity and service valuation affect the equilibrium strategy of the customers and the premium price charged for the maximum profit.

3 - Obtaining inter-departure times for two customer types
Eliran Sherzer, Opher Baron, Dmitry Krass, Oded Berman

Queueing networks that do not fall under the BCMP product form are quite complex. One of the main challenges is inter-departure times, which are also the inter-arrival times of the next queue. In an attempt to evaluate the distribution of the inter-departure times, the following queue is considered. There are two customer types, 0 and 1, which arrive from a Poisson process with different rates. Both customer types require exponential service but with different services.

Without the loss of generality, we propose a way to obtain the inter-departure of two type 1 departures. This is done by first decomposing all the possible scenarios to the number n of type 0 customers that departed between two type 1 customers (and truncate n at some point leaving a small error). Then further decompose them by the arrival epochs of both type 0 and 1 customers.

We show that all possible scenarios follow a general Erlang distribution. Further, we show that all possible scenarios and their marginal probabilities can be obtained using a simple mathematical recursion. Finally, despite the fact that there are over hounded of millions of scenarios, they all boil down to only a couple of thousand unique general Erlang.

To conclude, we are left with a weighted sum of several general Erlangs, which implies that both CDF, PDF, LST, and the moments can be computed straightforwardly.

4 - Stochastic approximation of symmetric Nash equilibria in queueing games
Ran Snitkovsky, Liron Ravner

We suggest a novel stochastic approximation algorithm to compute a Symmetric Nash Equilibrium strategy in a general queueing game with a finite action space. The algorithm involves a single simulation of the queueing process with dynamic updating of the strategy at regeneration times. Under mild assumptions regarding the regenerative structure of the process the algorithm converges to a symmetric equilibrium strategy almost surely. This yields a powerful tool that can be used to approximate equilibrium strategies in a broad range of strategic queueing models in which direct analysis is impracticable.

■ TE-62

Tuesday, 16:30-18:00 - Virtual Room 62

Juan Miguel Morales González

Stream: Keynotes
Keynote session
Chair: *Dolores Romero Morales*

1 - Data-driven power systems
Juan Miguel Morales

Thrilling yet challenging times lie ahead for the electrical power industry. The development of microgrids, the growing contribution of weather-driven renewable energy sources, the greater involvement of power consumers, and the increasing exchange of electricity among neighboring regions, all demand solid innovations in the way we plan and operate what is, most likely, the most colossal infrastructure ever built by Homo sapiens: The power grid. Furthermore, the extensive monitoring of this grid, together with the proliferation of technologies for intelligent control and computations, is creating countless opportunities for the exploitation of the massive amount of data that power systems generate in pursuit of a long-overdue modernization of ageing infrastructure and ambitious sustainability goals. In this talk, we will show examples of how ideas from the fields of machine learning, optimization and decision-making can be put to work together to develop novel data-driven operational and planning methods that facilitate the imperative transformation of current power grids into sustainable, reliable, secure and cost-efficient cyber-physical systems. We will discuss a variety of data-driven methods of different complexity, some of which are surprising for their apparent simplicity but remarkable benefits in terms of computational costs and/or social welfare, proving the huge potential value in the data still to be unleashed. Moreover, we will show that all agents involved in the power sector, namely, producers, consumers, retailers, operators, planners, etc. can profit from the smart use of data.

■ TE-63

Tuesday, 16:30-18:00 - Virtual Room 63

YoungWomen4OR - Energy Optimisation

Stream: YoungWomen4OR
Invited session
Chair: *Paula Carroll*

1 - On the impact of using Operations Research for Offshore Wind Energy in practice
Martina Fischetti

Sustainability is a pressing issue for our society. The demand for renewable sources of energy is growing and more companies are investing in green energies. Companies need to find innovative solutions to deliver renewable energies at lower costs. I worked in Vattenfall (a leading energy company in North Europe) to deliver state-of-the-art optimization solutions to wind energy problems, aiming at reducing costs and increasing power production. Throughout my PhD I used advanced models and algorithms to design offshore wind farms. I worked on two very important aspects of offshore wind park design: wind farm layout optimization (wind turbine location) and offshore inter-array cable routing (electrical connection between turbines). This project is a pioneering application of advanced OR to offshore wind farm design problems in practical applications. Our results show that combinatorial optimization methods, applied to the Wind Farm Layout Problem and to the Cable Routing problems, can make a huge impact—with savings in the order of 10-15M EUR for each wind farm. The tools I developed have been used to design the wind farm Hollandse Kust Zuid in the Netherlands. It will be the first wind farm ever constructed subsidy free. This is a great achievement not only for Vattenfall but for the whole wind energy business, and shows that OR can make an impact in our journey to a more sustainable future. The talk will give an overview of my PhD work and of my current work in Vattenfall

2 - An Adaptive Robust Optimization Approach for Assessing Flexibility of Residential Demand Response
Meltem Peker, Ilias Sarantakos, Haris Patsios, Sara Walker

Residential demand response helps address concerns about increasing demand in residential sector by providing flexibility to distribution networks. Traditionally, customer's demand flexibility is used by the residential load aggregators to maximize their profits and provide services to other stakeholders, e.g. distribution system operators. However, large participation of customers in DR and uncertainties in load data have great influence on operational and planning decisions of aggregators. This study incorporates uncertainty in residential load models arising from customer behavior and preference. We investigate the impact of uncertainty associated with customer behavior on the decisions of aggregators while considering network constraints. We demonstrate the impact by applying our framework to two relevant aggregator objectives: (i) electricity cost minimization and (ii) peak load minimization. We develop an adaptive robust optimization model and adopt column and constraint generation algorithm to solve the proposed model. We investigate the decision of aggregators in terms of the amount of flexibility, time-window, location and number of households that the flexibility will be procured from, which are significantly affected by the uncertainties and choice of objective.

Tuesday, 18:30-20:00

■ TF-02

Tuesday, 18:30-20:00 - Bulding A, Room A5

Game Theory, Solutions and Structures II

Stream: Game Theory, Solutions and Structures
Invited session
Chair: *Juan Tejada*

1 - On algorithms to compute the average of awards rule
Iago Núñez Lugilde, Miguel Angel Mirás Calvo, Carmen Quinteiro Sandomingo, Estela Sanchez-Rodriguez

The analysis of conflicting claims problems is a topic of great interest: a scarce resource has to be divided or distributed among a group of claimants. A division rule is a way of associating with each claims problem a division between the claimants of the amount available. The average of awards rule assigns to each claims problem the expectation of the uniform distribution defined over the set of awards vectors, that is, the center of gravity of the core of the associated coalitional game. One of the techniques used in obtaining the centroid of a compound shape is the method of geometric decomposition. The method works by dividing the shape into a number of parts, that share no common volume, and then finding the overall centroid as the average of the centroid of each part weighted by its relative measure. Since the set of awards is a convex polytope, different algorithms for volume computation can be adapted to calculate the centroid of the set. A backward recurrence algorithm based on dividing a simplex into several pieces, being one of them the set of awards, is studied. We also present algorithms that rely not only on the well known Delauny tessellation but also on tessellations using pieces that are sets of awards of specific claims problems that cover large parts of the set of awards vectors. Moreover, we define a recursive algorithm to compute the average of awards rule through cones by using the faces of the polytope. Finally, the methods are compared.

2 - Average Weights and Power in Weighted Voting Games
Dariusz Stolicki, Daria Boratyn, Wojciech Słomczyński, Karol Życzkowski

We investigate a class of weighted voting games for which weights are randomly distributed over the standard probability simplex. We extend earlier results in Boratyn et al. (2020) by providing closed-form formulae of the expectation and density of the distribution of weight of the k-th largest player under a subset of the class of Dirichlet distributions; analyzing the average voting power of the k-th largest player and its dependence on the quota, obtaining analytical results for small values of n; and obtaining a closed-form formula for the distribution of a sum of weights of a winning coalition.

3 - Some game theoretic marketing attribution models
Juan Tejada, Elisenda Molina, Weiss Tom

In this communication, we propose a game theoretical approach to the marketing problem of designing multi-channel attribution mechanisms. Although some references will be made to an existing cooperative game model, the Sum Game, (Zhao et al. (2018) and Cano-Berlanga et al. (2017)) and to the museum pass game (Ginsburg and Zang (2003)), our communication will be mainly centered in an approach based on the bankruptcy problem. First of all, we shall note that the defined class of attribution bankruptcy problems is a proper subclass of the bankruptcy problems. As a consequence, a new and adequate characterization is needed for any proposed solution to this problem. Special attention will be put on the Constrained Equal Loss (CEL) and Proportional (PROP) rules as attribution mechanisms. Those solutions will be considered for the cases in which the order and the repetition of channels on the paths to conversion are taken into account or not.

■ TF-05

Tuesday, 18:30-20:00 - Building Δ, Room Δ105

Optimizing the energy transition (onsite)

Stream: Emerging technical and financial aspects of energy problems
Invited session
Chair: *Ruth Dominguez*

1 - Bidding strategy of a retailer with flexible consumers using SSD constraints
Ruth Dominguez, Sebastiano Vitali, Miguel Carrión

In this work, we consider a retailer that participates in the daily electricity markets to purchase/sell the electricity consumed/generated by its clients, which are mainly flexible consumers. Additionally, the retailer has a PPA contract with a renewable producer so that the retailer sells the generated power to the electricity markets. Thus, the objective of this work is to propose a methodology to determine the bidding strategy of the retailer considering different uncertainty sources, such as the electricity prices, the net consumption of its clients, and the generation from the intermittent renewable producer. Stochastic optimization is used to formulate the optimization problem. To define the best bidding strategy, second-order stochastic dominance (SSD) constraints are incorporated in the optimization model. Numerical results will be presented to show the outcomes of the proposed approach.

2 - Multi-objective optimization of the design and operation of multi-energy systems
Antoine Mallegol, Patrick Meyer, Mehrdad Mohammadi, Arwa Khannoussi, Bruno Lacarriere

In the energy transition of energy networks, multi-energy systems (MES) are promising technologies as they enable synergies between multiple energy carriers (electricity, gas, heat). Multi-objective optimization is then needed to determine both the optimal design of the energy conversion technologies and their operation parameters, over multiple objectives (e.g.: costs and environmental criteria). However, the objective functions of a MES model might not be linear, meaning some linearization techniques such as piecewise linear approximation must be used to write a mathematical model of a MES, introducing integer variables in the model.

This work presents first a mixed-integer linear programming (MILP) model to solve the problem of the optimal design and operation of a MES over two objectives. The limitations of this approach are then presented, and a new matheuristic model is proposed, in which a metaheuristic is used to solve the nonlinear parts of the model, i.e. the design of the MES, and a mathematical program is used to solve optimally the operation of the MES with respect to the constraints of the metaheuristic. This work is applied to the optimization of a MES in Nantes, France, using one year of historical data with an hourly resolution.

3 - Vertical Axis Wind Turbine Layout Optimization
Davide Cazzaro, Gabriele Bedon, David Pisinger

Vertical Axis Wind Turbines (VAWT) are an alternative to Horizontal Axis Wind Turbines for offshore wind farms. This technology is not mature, but it is expected to enable higher power densities than conventional turbines, because of the reduced wakes. In addition, the low center of mass makes it interesting for floating wind turbines applications. Finally, VAWTs are better suited to extract energy from low wind speeds, which can complement existing wind farms. The optimization of wind farm layouts —finding the optimal positions of wind turbines in a park— has proven crucial to extract more energy from conventional wind farms. In this study, we build an optimizer for VAWTs given a discrete set of positions, so to take into consideration arbitrarily shaped layouts as well as obstacles in the area. Moreover, we focus on developing a technique that scales well to large numbers of turbines. We adapt a recent model for the wakes of VAWTs to consider a troposkian design. We can then model a large VAWT, whose power capacity is comparable to HAWTs, on a real wind scenario, and assess for the first time the performances of a large wind farm operating troposkian VAWTs. We benchmark our optimization on realistic instances, showing that the heuristic scales to large wind farms, and analyze the optimized layouts obtained with VAWTs and with HAWTs. Finally, the reduction in wake losses obtained in the current test case is compared to the reductions available in literature.

■ TF-06

Tuesday, 18:30-20:00 - Building Δ, Room Δ103

Combinatorial optimization for distribution and logistics II

Stream: Combinatorial Optimization
Invited session
Chair: *Claudia Archetti*

1 - Crowd-sourced humanitarian relief vehicle routing problem
Javaiz Parappathodi, Claudia Archetti

During recent years, the number and scale of natural disasters have been increasing steadily. In view of this, a crucial aspect of humanitarian logistics is ensuring relief materials reach the needy in an efficient and quick manner. Crowd-sourcing is a concept that has been gaining momentum over the last few years as a high potential tool for improving disaster response. This paper defines a crowd-sourced humanitarian relief vehicle routing problem and proposes a heuristic to generate good quality solutions in reasonable time. The algorithm is based on an Iterated Local Search (ILS) scheme. Extensive computational studies are made on randomly generated instances to gain insights on the heuristic performance and on the impact of the problem features on solution quality. In addition, instances mimicking the shape of real cities are generated and results are analyzed.

2 - Freight Delivery using Public Transportation Systems: Mixed Integer Programming Approaches for Operational Decision Making
Minakshi Punam Mandal, Claudia Archetti

The aim of this study is to explore the potential of using public transportation systems for freight delivery. The idea is to use the spare capacities, particularly during off-peak hours, of the public transportation vehicles like buses, trams, trains, etc. to transport packages within the city, instead of dedicated delivery vehicles. This is aimed towards not only reducing the cost of delivery, but also congestion, traffic, and the resulting negative impacts on the environment. The study contributes towards the growing body of literature on innovative strategies for performing sustainable last-mile deliveries. We study the problem at an operational level, where packages are transported from the Consolidation Distribution Center (CDC) to the pre-determined public vehicle stops by the delivery vehicles, from where they are transported into the city by the public transportation systems. Then the last leg of the delivery of the packages is performed using green vehicles or eco-friendly systems to their respective customers. We propose mixed integer linear programming approaches to study the routing problem of the packages from the CDC to the customers, and provide numerical experiments to study the efficiency and effectiveness of the study.

3 - Freight on Public Transport: Strategical decision making with mixed integer programming
Diego Delle Donne, Laurent Alfandari, Claudia Archetti, Ivana Ljubic

Freight transportation is a key issue within big cites involving a significant amount of activities with undesirable consequences on the traffic, the environment and subsequently on human health. Most big cities in the world are facing significant challenges related to the congestion and pollution generated by the number of vehicles within urban areas. Freight transportation vehicles represent a significant portion of this volume and their number is expected to continue increasing due to new business models. Recent studies have shown the viability of innovative strategies for performing sustainable last-mile delivery operations by integrating existing public transportation services (PTS) into city logistics related to freight delivery. The idea is to use PTS to carry parcels between some predetermined points in the city, replacing usual freight transportation vehicles, and completing the last part of the routes with small, "green" vehicles. Many challenges arise on strategical, tactical and operational aspects of the proposed methodologies. In this work, we focus on the strategical stage, which asks to select a subset of city resources (i.e., bus lines, bus stops) to maximize the potential freight flow through the city restricted to strategical and budget constraints. We propose different Mixed Integer Programming approaches for this problem and perform an exhaustive computational experimentation to test the practical contribution of the proposed models.

4 - A tailored Benders decomposition approach for last-mile delivery with autonomous robots
Laurent Alfandari, Ivana Ljubic, Marcos de Melo da Silva

We address an operational problem of a logistics service provider that consists of finding an optimal route for a vehicle carrying customer parcels from a central depot to selected facilities, from where autonomous devices like robots are launched to perform last-mile deliveries. The objective is to minimize a tardiness indicator (maximum or total tardiness, or number of late deliveries) based on customer deadlines. We study the problem complexity, devise a unified Mixed Integer Programming formulation and propose an efficient branch-and-Benders-cut scheme to solve instances of realistic size, with a tailored combinatorial algorithm for the Benders subproblem. Our results indicate our solution approach is computationally more efficient than other alternatives. We also derive managerial insights, analyzing how the number of available facilities, the coverage radius of autonomous robots and their travel speeds affect late deliveries and environmental criteria such as CO2 emissions. Our findings suggest that improving the infrastructure (either by making more distribution facilities available, or allowing dedicated tracks where autonomous robots can operate at higher speeds) significantly improves the quality of service.

■ TF-07

Tuesday, 18:30-20:00 - Building Δ, Room Δ102

Urban and Territorial Planning in MCDA 1

Stream: Multiple Criteria Decision Analysis
Invited session
Chair: *Isabella Lami*

1 - Multi-Criteria Decision Making for Urban and Architectural Sustainable Development: a systematic review
Beatrice Mecca

In the current climate emergency, urban and architectural choices need to fulfil the sustainability objectives of the Agenda2030, aiming at an innovative and sustainable future. It is therefore interesting to observe how sustainability concepts have been considered so far in decision-making processes concerning the urban and architectural context and how MCDA methods supported them. Accordingly, this paper aims to provide a systematic review of the literature on the use of MCDA in sustainable urban and architectural development context. The papers analysed, which have been published since the Agenda2030's introduction to now, deal with decision-making in sustainable urban and architectural development contexts. Descriptive statistics, tables and graphics are provided to highlight the main trends and gaps according to specific research questions. Particularly, the type of sustainability criteria considered and the possible conjunction of MCDA methods with scenario building tools are investigated to legitimise and lay the basis for future doctoral research.

2 - Planning the development of an ecovillage with a decision support process based on a combinatorial optimization space-time model
Isabella Lami, Salvatore Greco, Maria Barbati

The paper illustrates the first application to a real decision problem of the space-time model for combinatorial optimization problems developed by Barbati, Corrente, Greco (2019). The model permits to handle complex problems using several methodologies including multiple attribute value theory and multiobjective optimization. We illustrate the model with a real decision problem concerning how to realise an ecovillage located in Piedmont (Italy) in the next four years, aimed at a socially and culturally active self-sufficiency in the area. The developer has purchased an entire mountain village, divided into two nucleus, and it has around it many hectares of land and forest, as well as other villages and rural cottages abandoned for decades, which are potentially future enlargements. The topic is extremely current: the debate on new forms of progress, living and working is sweeping across Europe and beyond. The objectives of the ecovillage are: i) social, i.e. the repopulation of internal territories while encouraging urban decongestion; ii) economic, i.e. the self-sustainability with a low environmental impact; iii) environmental, i.e. the protection of the territory, now abandoned, thanks to the presence of new residents; iv) social and cultural. The application of the model has allowed the developer to consider all these aspects when choosing among different possible locations available for each function that will compose the village.

3 - A novel application of the Analytic Hierarchy Process (ANP) in measuring territorial vulnerabilities for planning the adaption. Insights from a practical application
Francesca Abastante, Ombretta Caldarice, Grazia Brunetta

Cities and their regional systems are exposed to global changes more and more. Assuming the best decision to manage territorial vulnerabilities towards adaptation is a complex problem that requires to consider a plurality of points of view. In this context, Multiple Criteria Decision Analyses (MCDA) are very useful tools to harmonise different prospective coming to a general picture of the most vulnerable area. They constitute an important step for an effective planning initiative toward adaptation. Starting from this assumption, this research aims to offer insights from a practical application of an Analytical Hierarchy Process (AHP) model developed in the Specializing Master's Programme in Resilient Territories led by the Responsible Risk Resilience Centre - R3C. Based on the pairwise comparisons, this application builds the prioritisation of sensitivities and hazards indicators that composed the R3C matrix designed to measure territorial vulnerabilities at the local scale. In particular, the AHP is used to: • Identify a prioritisation of hazards concerning each sensitivity indicator; • Identify a prioritisation of hazards in absolute terms. As a final goal, this application of AHP for measuring territorial vulnerabilities directs the challenge of strengthening institutions' capacity to understand the impacts of territorial vulnerabilities, engaging public organisations, technicians, and individuals in the adaption pressure.

■ TF-08

Tuesday, 18:30-20:00 - Building Δ, Room Δ101

Online and Omnichannel Retailing II

Stream: Demand and Supply in Consumer Goods and Retail
Invited session
Chair: *Alexander Hübner*

1 - Assortment optimization in omni-channel retailing
Alexander Hübner, Jonas Hense

Nowadays the majority of retail customers use multiple channels in their purchasing process. It is therefore essential to consider customers' channel interactions when deciding on assortments. We investigate the assortment, space and inventory problem for an omni-channel retailer operating with interconnected bricks-and-mortar stores and an online shop. Current literature mainly focuses on single-channel assortments and ignores channel interactions such as cross-channel substitution. We contribute the first integrated omni-channel model with stochastic demand, space-elastic demand and out-of-assortment and out-of-stock demand both for in-channel substitution and cross-channel substitution. A specialized heuristic was applied to solve our model. Our approach achieves near-optimal results for small instances and higher objective values as alternative approaches for larger instances. With the full integration of channels and equal costs across channels, omni-channel retailers can realize a significant profit increase that also depends on the magnitude of substitution rates and the cost differences between channels. We further show numerically that in-channel substitution has a stronger impact on profits than cross-channel substitution when costs are equal across channels.

2 - A Personalized Content-Based Recommendation System for Online Retailers
Alireza KabirMamdouh, Gurhan Kok

A critical decision for online retailers is to select the products to present to the customers on a web-page out of thousands of products. Online retailers may prefer to offer a different set for each customer because customers have heterogeneous preferences. To find the optimal set to offer, we need to know the customer's preferences. We propose a new personalized content-based method specially designed for online retailers. We focus on customers' activities at an online store, such as clicks, and purchases, more than the feedbacks such as ratings or comments. This property is useful for online retailers where there are fewer rating feedbacks, but there are several search sessions including clicks and purchases. We design a method based on attribute vectors and customers' activity history. We represent each product with an attribute vector. For each product, the corresponding attribute vector consists of all explicitly known attributes and features of a product, e.g. color, price level, and brand. For each customer, a score of interest is assigned to each attribute vector, representing his/her interest in that combination of attributes. This score is calculated based on the customer's history. We test the method using a dataset provided by an apparel retailer. Our method outperforms benchmark methods (Collaborative filtering, Popular products, and MNL choice model) estimating purchases in general, and it has a strictly better performance in recommending new products.

3 - In-store picker routing problem: a new problem for omnichannel retail
Pedro Amorim, Fábio Moreira

Online retail had a large growth due to the pandemic context of 2020. Since large retailers have part of their stock in physical stores, new operations were built for picking products that are in the store shelfs to serve e-commerce orders. However, it is very hard to find products in a layout that is not prepared for efficient picking. Moreover, having numerous picking teams in-store adds many inconveniences to the shopping experience of the customers (e.g., congested aisles). In this setting, a team of pickers needs to pickup shopping lists in-store. Therefore, providing efficient shopping paths will allow the team to pickup orders by following the fastest and shortest routes that avoid congested aisles, not to disturb the shopping experience of the customers. To understand the dynamics of a store, it is important to have data describing the state of each aisle throughout the day, promotions offered in each area, and the positions of shelf replenishing teams. In this work, we aim at providing each picker a decision tool that indicates the best path to take from its current position to the next product to pick. The intuitive solution is to follow the shortest path, but due to store dynamics, the picker may be suggested a longer path. Our work shows the impact of these different scenarios.

4 - Retail logistics and customer behavior: A systematic review
Christoph Baldauf

How customers search for and purchase products has significantly changed with online and omnichannel retailing. In today's retail environment, customers are getting increasingly into direct contact with logistics, and retailers share more and more operations-related information with them. As a result, retail logistics are transforming from a back-office operation focusing on cost-effectiveness to playing a strategic role in affecting customer behavior and differentiating from competitors. In this paper, we systematically review 40 peer-reviewed academic journals to assess the current state of knowledge on the strategic role of retail logistics in online and omnichannel retailing and its impact on customer purchase, repurchase, and return behavior. We focus on research from the operations and marketing fields since retailers nowadays have to follow an integrative approach considering the interdependencies between these functions to operate successfully. Findings reveal that apart from general increases in logistics performance (e.g., lead-time reductions), the disclosure of logistics information such as inventory levels, and increasing choices and flexibility given more product, delivery, and return options affect customer behavior. We use these insights to draw theoretical and managerial implications, and to present promising avenues for future works on the strategic role of retail logistics, ideally leading to the generation of sustainable competitive advantage.

■ TF-21

Tuesday, 18:30-20:00 - Virtual Room 21

Methodological and practical contributions of Soft OR/PSMs to Policy Making - Session B

Stream: Soft OR and Problem Structuring Methods
Invited session
Chair: *Irene Pluchinotta*
Chair: *Ine Steenmans*

1 - Soft OR as a Problem Structuring Method: Three Case Studies
Michael Howlett, Ching Leong

Ching LEONG, NUS Michael Howlett SFU

The inadequacy of quantitative risk analysis led to the emergence of engaging multiple stakeholders in successfully designing and implementing risk management measures in "Soft OR" (Douglas, 1985; Renn 1998). Numerous authors have stated the need to investigate social risk perception in risk management, since the reality perceived affects stakeholders' decisions, and could lead to failures in risk management actions (Bickerstaff, 2004, Harclerode et al., 2016). Risk perception, local knowledge, and individual and collective attitudes in managing and adapting to hazards are strongly influenced by social and cultural factors that reflect the values and history of a community (Harclerode et al., 2016).

The role of individualistic risk perception to identify and formulate risk management decisions imbricates with the problem definition in Soft OR, hence indicating the relevance of PSM in implementing risk solutions. To further study the influence of Soft OR in Policy Implementation and Risk Management, three case studies have been reviewed to collate empirical evidence.

2 - The need for problem structuring in modelling the transition to net-zero emissions
Rachel Freeman

Transitioning energy systems to net-zero emissions is an immediate challenge across the world. It requires policy intervention in a complex system of energy demand and supply, influenced by social, technical, economic and political factors. Energy system models used in policy generally represent well-bounded parts of the whole system. As the depth of decarbonisation increases, and system changes become more fundamental and risky, policy makers need to understand whole system dynamics. Expanding model boundaries simultaneously increases modelling complexity, uncertainty about how to represent the real world, and the difficulty of model validation. A longer process of problem structuring is needed before model building starts. For example, defining a meta-theoretical framework, identifying concepts from other disciplines that can be used in the model, and creating ordinal scales to parametrise previously unmeasured values. This talk will describe how this problem structuring process was done in the creation of a system dynamics simulation model of the UK's energy transition. The model endogenises political and social factors normally not included. Lessons learned during the model theorising, design, build, and calibration processes will be presented, along with a proposition for improving problem structuring in future. Responses from government policy experts, during a seminar that presented the model and its findings, will be discussed.

3 - Power/knowledge and decision support to environmental policy making
Yves Meinard

Soft OR, PSM and, more generally, decision support sciences, are academic disciplines and associated consulting practices based on the idea that scientific knowledge has a role to play in improving decision making and policy making. This seemingly innocuous assumption is questioned by a growing body of literature, whose distinctive aim is to demonstrate that scientific knowledge is interwoven with power relations. This line of thought originates in the works of the French philosopher Michel Foucault, and has now been applied to numerous critical analyses of science-based policies, including in the environmental domain, which will be my main focus. I will argue that analyses of power/knowledge can be useful to improve the theory and practice of decision support. This is because these critical analyses can unveil hidden influences skewing expert advices and highlight uncritically accepted questionable assumptions. However, based on an analysis of the work of Foucault and some prominent applications of his ideas to environmental policy making, I will show that the literature on power/knowledge is also plagued by several damaging weaknesses. These weaknesses stem from a lack of conceptual coherence, which creates terminological confusion and eventually leads many authors to voice grandiloquent conclusions that do not follow from their premises and reasoning. I conclude by explaining how power/knowledge can improve decision support to policy making, while highlighting its limits.

■ TF-22

Tuesday, 18:30-20:00 - Virtual Room 22

Multi-level optimization for energy management II

Stream: Bilevel Optimization
Invited session
Chair: *Sonja Wogrin*
Chair: *Afzal Siddiqui*

1 - Distributional Energy Justice via Multi-Objective Optimization for Energy System Planning
Yury Dvorkin

This presentation will discuss a notion of distributional energy justice and integrate it into energy system planning, with a particular focus on quantifying its implications on tariff design practices. Since distributional justice concerns fairness in the process of sharing costs and benefits, we will use a multi-objective optimization framework to model and trace the effects of environmental, societal, public health benefits and costs as part of energy system planning for New York City, NY. Our case study will use this multi-objective optimization to investigate imperfections of different tariff design policies (e.g. value stack, net metering, distributional marginal pricing) and their impacts on urban communities.

2 - Electricity-Gas Systems and the Impacts of a Attacks on coupled Infrastructure
Alberto J. Lamadrid L

In this research, we study (1) propose a coordination scheme for the day-ahead schedule of natural gas and electricity systems; (2) define a new class of false data injection (FDI) cyber-attacks on the gas demand and scheduling information of the natural gas system; and (3) investigate the impacts of such attacks on the operation of both energy systems. The coordination mechanism consists of nested optimization problems. The natural gas system scheduling step in the mechanism is modeled as a bi-level max-min optimization problem with consideration of attacks. We use a column and constraint generation (C&CG) algorithm to solve this bi-level problem. The coordination mechanism and bi-level attack problem are examined using a case study based on the IEEE test systems

3 - Prosumer Power? Optimal Distributed Energy Resource Investment in a Deregulated Electricity Industry
Afzal Siddiqui, Sauleh Siddiqui

Prosumers adopt distributed energy resources (DER) to cover their own consumption and to sell energy in the electricity market. Although prosumers are too dispersed to exert market power in electricity markets, they may hold a strategic advantage over conventional generators in selecting DER capacity. We devise a bi-level model to examine DER capacity sizing by prosumers in an electricity market where generators have market power. At the upper level, a prosumer chooses DER capacity in anticipation of lower-level operations by generators and DER output. In particular, we demonstrate that generator market power and the marginal cost of conventional generation affect DER investment by a strategic prosumer in an unexpected manner. Intuitively, a prosumer facing generators with market power (MO) invests in more DER capacity than under a perfectly competitive generation sector (PC) in order to take advantage of a high market-clearing price. However, if the marginal cost of generation is "too high," then a prosumer under PC actually adopts more DER capacity than under MO as the high marginal cost of generation prevents the market-clearing price from diminishing significantly from competition. Moreover, competition relieves the choke on consumption under MO, which further incentivises the prosumer to expand DER capacity in order to capture market share. We prove the existence of a critical threshold for the marginal generation cost that leads to this counterintuitive result.

4 - Anticipative Coalitional Stability in Cross-Border Transmission Expansion Planning
David Pozo

Cooperative Game Theory has found extensive application in power systems research. The solution concepts have been successfully exploited to address the issues of transmission cost allocation, international cooperation in electricity trading, microgrids coordination, allocation of power losses, allocation of firm energy rights, etc. However, all the applications mentioned suffer from a drawback: Cooperative Game Theory is used as an ex-post analysis step. Planning and operation decisions in existing models are usually separated from the allocation mechanisms. Unfortunately, such an approach could lead to coalitional stability issues, which may hamper cooperation. We propose a bilevel optimization framework for explicitly incorporating Cooperative Game Theory principles into planning problems in this talk. Using a 4-system case study, we demonstrate that it is possible to identify optimal planning decisions in an anticipating manner, subject to the resulting cooperative game's properties.

■ TF-23

Tuesday, 18:30-20:00 - Virtual Room 23

Applications of Optimization in Engineering II

Stream: Engineering Optimization
Invited session
Chair: *Kevin-Martin Aigner*

1 - Solving AC Optimal Power Flow with Discrete Decisions to Global Optimality
Kevin-Martin Aigner, Robert Burlacu, Frauke Liers, Alexander Martin

We present a solution framework for general alternating current optimal power flow (AC OPF) problems that include discrete decisions. The latter occurs, for instance, in the context of the switching of power generation units and transmission lines or the curtailment of renewables. Our approach delivers globally optimal solutions and is provably convergent. We model AC OPF problems with discrete decisions as mixed-integer nonlinear programs. The solution method is essentially based on using piecewise linear relaxations that we model as mixed-integer linear programs. These relaxations are adaptively refined until some termination criterion is fulfilled. The method is complemented by problem specific mixed-integer second-order cone programs that deliver tight dual bounds. Finally, we present extensive numerical results for various discrete AC OPF problems that demonstrate the applicability of our method. Even for instances with a large proportion of discrete decisions we are able to generate high quality solutions efficiently.

2 - Predicting optimal ABC zone sizes in manual warehouses
Allyson Silva, Kees Jan Roodbergen, Leandro Coelho, Maryam Darvish

In manual warehouses, pickers walk in the storage area to retrieve products from pick lists. The storage location assignment problem (SLAP) determines where to store products to minimize the expected average route length traveled by pickers. The SLAP is usually solved using simple policies. The most popular one is the ABC policy, which splits the storage area into three zones and the products to be stored into three classes. The class with the most demanded products is assigned to the zone with the best storage locations. Despite the method's popularity, arbitrary values are still commonly used for the size of each zone. These may lead to major efficiency loss in many common warehouse settings. In this study, we identify features that most impact the optimal zone sizes, such as the warehouse layout, pick list characteristics, and the rules used to decide the shape of zones and to create the routes. This analysis is made from data generated from extensive simulations to obtain the best zone sizes under different conditions. Four machine learning regression models are trained to predict optimal zone sizes from this data. We discuss the trade-offs between applicability and performance of each one. We show that the sizes predicted significantly improve the picking efficiency, both in the average and worst-case scenarios, compared to those commonly used in practice, including the random policy, a two-zone system with a 20/80 rule, and a three-zone system with classical ABC values.

3 - An optimization model for the management of green areas
Patrizia Daniele, Daniele Sciacca

Global warming, especially in recent decades, has been and continues to be one of the most worrying problems to solve. The progressive increase of the world population and all the related activities, such as energy consumption, transports, industrial activities, will cause an increase in CO2 concentrations, and not only, in the atmosphere. We present an optimization model for the management of the green area in order to find the optimal green surface to absorb CO2 emissions of industrialized cities. We obtain a minimization problem and the related variational inequality. We study the Lagrange theory to better understand the process that regulates the possible increase in green space.

■ TF-25

Tuesday, 18:30-20:00 - Virtual Room 25

Advances in Distributionally Robust Optimization and Risk Averse Optimization

Stream: Stochastic and Robust Optimization
Invited session
Chair: *Francesca Maggioni*

1 - Bounds for Multistage Mixed-Integer Distributionally Robust Optimization
Francesca Maggioni, Guzin Bayraksan, Daniel Faccini, Ming Yang

Multistage mixed-integer distributionally robust optimization (DRO) forms a class of extremely challenging problems since their size grows exponentially with the number of stages. One way to model the uncertainty in a multistage setting is by creating sets of conditional distributions (the so-called conditional ambiguity sets) on a finite scenario tree and requiring that such distributions remain close to nominal conditional distributions according to some distance (e.g., phi-divergences or Wasserstein distance). In this paper, new lower bounding criteria for this class of difficult decision problems are provided through scenario grouping using the conditional ambiguity sets associated with various commonly used phi-divergences and the Wasserstein distance. We also show that, for a special case of Cressie-Read Power divergence, another way to obtain the same results is to consider the risk envelope corresponding to the ambiguity set. Our approach does not require any special problem structure such as convexity and linearity. Therefore, while we focus on multistage mixed-integer DRO, our bounds can be applied to a wide range of DRO problems including two-stage and multistage, with or without integer variables, nested or non-nested formulations. Extensive numerical results on a mixed integer multistage production problem show the efficiency of the proposed approach over different choices of partition strategies, phi-divergences, and levels of robustness.

2 - Designing Interpretable Policies in Two-stage Distributionally Robust Optimization
Eojin Han, Chaitanya Bandi, Omid Nohadani

In many real applications, practitioners prefer policies that are interpretable and easy to implement. This tendency is magnified in sequential decision making settings. In this paper, we leverage the concept of finite adaptability to construct policies for two-stage optimization problems under distributional uncertainty. The aim is to construct policies that have provable performance bounds. This is done by partitioning the uncertainty realization and assigning a contingent decision to each piece. We first show that the optimal partitioning can be characterized by translated orthants, which only require the problem structure and, hence, are free of modeling assumptions. We then prove that finding the optimal partitioning is hard and propose a specific partitioning scheme with orthants, allowing the efficient computation of orthant-based policies via solving a mixed-integer optimization problem of a moderate size. By leveraging the geometry of this partitioning, we provide performance bounds of the orthant-based policies, which also generalize the existing bounds in the literature. These bounds offer multiple theoretical insights on the performance, e.g., its independence on problem parameters. We also assess suboptimality in more general settings and provide techniques to obtain lower bounds. The proposed policies are applied to a stylized inventory routing problem with mixed-integer recourse.

3 - Kernel methods for distributionally robustness in optimization and machine learning
Jia-Jie Zhu

We study the use of reproducing kernel Hilbert spaces (RKHS) as the dual spaces for enforcing distributional robustness in stochastic optimization and machine learning. We prove a generalized variational duality for DRO using the integral probability metrics (IPM), of which the type-1 Wasserstein metric is a special instance. We pay special attention to the function approximation aspect of distributionally robust optimization (DRO), by comparing the Moreau-Yosida regularization used in Wasserstein DRO and our proposed kernel-based function approximations. Our analysis highlights the roles that function approximation plays in enforcing distributional robustness, especially when used with loss functions involve complex function classes.

4 - Risk-averse Allocation Indices for Multi-armed Bandit Problem
Ozlem Cavus, Milad Malekipirbazari

In classical multi-armed bandit problem, the aim is to find a policy maximizing the expected total reward, implicitly assuming that the decision maker is risk-neutral. On the other hand, the decision makers are risk-averse in some real life applications. In this study, we design a new setting based on the concept of dynamic risk measures where the aim is to find a policy with the best risk-adjusted total discounted outcome. We provide a theoretical analysis of multi-armed bandit problem with respect to this novel setting, and propose a priority-index heuristic which gives risk-averse allocation indices having a structure similar to Gittins index. Although an optimal policy is shown not always to have index-based form, empirical results express the excellence of this heuristic and show that with risk-averse allocation indices we can achieve optimal or near-optimal interpretable policies.

■ TF-26

Tuesday, 18:30-20:00 - Virtual Room 26

Linear complementarity problems and their applications

Stream: Nonlinear Optimization
Invited session
Chair: *Marianna Eisenberg-Nagy*
Chair: *Petra Renáta Rigó*

1 - A full Newton-step interior-point method for weighted linear complementarity problem
Goran Lesaja, Zsolt Darvay, Soodabeh Asadi Dezaki, Nezam Mahdavi-Amiri, Florian Potra

The Weighted Linear Complementarity Problem (WLCP) has been introduced recently as a generalization of the Linear Complementarity Problem (LCP) with a modified complementarity equation where zero on the right-hand side is replaced with the nonnegative weight vector. Some important problems in economics, science, and engineering can be formulated as WLCP models. Hence, efficient methods for solving WLCP are of interest. In this talk, a full-Newton step Interior-Point Method (IPM) for solving the monotone WLCP is proposed and analyzed. Since the algorithm takes only full-Newton steps, the calculation of the step size is avoided. It is also shown that under suitable conditions the proximity measure to the target point on the central path reduces quadratically at each iteration. Furthermore, with an appropriate choice of barrier and threshold parameter, iterates are shown to stay in the certain neighborhood of the central path, that is, the algorithm converges to the $varepsilon$- solution of the WLCP. Moreover, the iteration bound for the algorithm coincides with the best iteration bound obtained for these types of methods.

2 - Sufficient matrices and linear complementarity problems
Tibor Illés

Sufficient matrices (SU) have been introduced by Cottle et al. (1989). The class of P*(κ)-matrices, for given nonnegative real parameter κ, has been defined by Kojima et al. (1991). The union for all possible κ parameters of P*(κ)-matrices forms the class of P*-matrices. Väliaho (1996) proved that the P*-matrices are exactly those which are sufficient. Unfortunately, there are two important, negative results related to sufficient matrices. P. Tseng (2000) proved that decision problem related to the membership of matrices for P0- and column sufficient matrices are all co-NP-complete.

The aim of this talk to overview several properties of sufficient matrices and their relation to linear complementarity problems.

3 - Detection sufficient matrices by linear and non-linear programming
Janez Povh, Marianna Eisenberg-Nagy, Anita Varga, Janez Žerovnik, Tibor Illés

In this talk we present some recent results related to detecting sufficient matrices. We first present new characterizations of these matrices which imply novel necessary and sufficient conditions for matrix sufficiency.

We use these results to develop algorithms with exponential iteration complexity which in each iteration solves a simple instance of linear programming problem and is capable to reveal whether a given matrix of dimension at most 20 is sufficient or not. This algorithm demonstrates almost 100 % accuracy on all tested instances of matrices and also provides certificates for the non-sufficient matrices.

We have also implemented a parallel version of this algorithm and a non-linear programming model for sufficiency. All these approaches were benchmarked against the well-known Valiaho's algorithm, for which we also developed a Matlab implementation. We present extensive numerical results which reveal that the new approaches have several advantages, but the Valiaho's algorithm remains very competitive.

4 - Predictor-corrector interior-point algorithm for solving sufficient linear complementarity problems based on a new search direction
Petra Renáta Rigó, Tibor Illés, Zsolt Darvay

We present a new predictor-corrector interior-point algorithm for sufficient linear complementarity problems. The novelty of the algorithm consists in using a new type of algebraic equivalent transformation on the system defining the central path. In this new approach we use the square function in order to define the search directions. It can be shown that the obtained search directions can be derived from positive-asymptotic kernel function. We prove that the proposed algorithm has polynomial complexity in the handicap of the problem's matrix, the size of the problem and the bitsize of the data. This is the first predictor-corrector interior-point algorithm for solving sufficient linear complementarity problems using the square function in this new type of algebraic equivalent transformation technique.

■ TF-27

Tuesday, 18:30-20:00 - Virtual Room 27

Robust, federated, and distributed learning

Stream: Big Data and Optimization
Invited session
Chair: *Dusan Jakovetic*

1 - EFIX: Exact Fixed Point Methods for Distributed Optimization
Nataša Krklec Jerinkić, Dusan Jakovetic, Natasa Krejic

We consider strongly convex distributed consensus optimization over connected networks. EFIX, the proposed method, is derived using quadratic penalty approach. In more detail, we use the standard reformulation – transforming the original problem into a constrained problem in a higher dimensional space – to define a sequence of suitable quadratic penalty subproblems with increasing penalty parameters. For quadratic objectives, the corresponding sequence consists of quadratic penalty subproblems. For the generic strongly convex case, the objective function is approximated with a quadratic model and hence the sequence of the resulting penalty subproblems is again quadratic. EFIX is then derived by solving each of the quadratic penalty subproblems via a fixed point (R)-linear solver, e.g., Jacobi Over-Relaxation method. The exact convergence is proved as well as the worst case complexity. In the case of strongly convex generic functions, the standard result for penalty methods is obtained. Numerical results indicate that the method is highly competitive with state-of-the-art exact first order methods, requires smaller computational and communication effort, and is robust to the choice of algorithm parameters.

2 - Towards more robust neural network models with Negative Deep Learning
Nemanja Milosevic, Miloš Racković

With the recent developments and discoveries in the field of Deep Learning, it is very clear that Deep Neural Network models can be used and applied to various problems and fields. Deep Learning models can be and are used every day in various scenarios, and some of these scenarios can be described as critical, human life influencing scenarios. In these cases it is very important to use models which have a high degree of robustness and accuracy even in difficult scenarios. For example, in critical systems of self driving cars, the models need to perform well even if the sensors or cameras are malfunctioning in some way. These malfunctions can be simple, e.g. a dirty camera lens, but the models must detect and adapt to these malfunctions. In this session we will present one family of Deep Learning models which we will demonstrate is more robust in different difficult situations. Specifically, we will concentrate on Deep Neural Network models which are used for image processing and common problems which can occur in real-life situations such as occlusions, partial input recognition, image corruption and others. We will define and demonstrate how one can use Negative Deep Learning models in these scenarios and why we think they outperform normal models which we use today. We will also demonstrate how our approach can be applied to existing Convolutional Neural Network models with little modifications to existing architectures.

3 - Decentralized stochastic non-convex optimization
Usman Khan, Ran Xin, Soummya Kar

Decentralized optimization over networked nodes has been a topic of significant recent research. In this talk, we describe our recent works on stochastic non-convex problems that frequently arise in modern machine learning and signal processing. In particular, we present a family of decentralized algorithms, based on gradient tracking (and variance reduction), that achieve provably fast and robust performance for several classes of problems. We further identify the regimes of practical interest where these methods achieve network topology-independent performances and hence linear speedup compared with their centralized counterparts on a single node. Numerical experiments are included to demonstrate our theoretical findings.

■ TF-28

Tuesday, 18:30-20:00 - Virtual Room 28

Methods for Learning from Data

Stream: Mathematical Optimization and Data Science
Invited session
Chair: *James Brooks*

Chair: *José Dulá*

1 - **Competing DEA procedures: testings and comparisons**
Gregory Koronakos, José Dulá, Dimitris Despotis

"BuildHull" is an algorithm developed to speed up data envelopment analysis (DEA) computations for large-scale efficiency assessments. Since its appearance in 2011, BuildHull has generated interest in its design and performance motivating comparisons and competition. We report on investigations about recent challengers to BuildHull's long primacy. This entails a discussion of the design of the new procedures for DEA competing directly with BuildHull as well as computational results from their implementations. This presentation will reveal the results of this competition.

2 - **Optimizing the Return from a Machine Learning Model when Resources are Constrained**
Shannon Harris, Jerrold May, Luis Vargas, Johnson Moore

Lift is a measure of performance that is used to calculate the effectiveness of a targeted classification model, and can consider the resources expended in applying a model. Resource constrained applications in machine learning models are common in industries such as marketing and healthcare, where it may only be feasible to solicit the most likely customers in direct marketing, or to apply intensive medical treatment to the patients in greatest need of care. In this paper, we propose a new mixed-integer linear programming model to maximize lift, demonstrate that it achieves greater lift than do traditional machine learning models, and discuss the generalization properties of its solutions. We illustrate our model using a commonly used bank marketing dataset.

3 - **Nearest convex hull classification with linear programming**
José Dulá, Anatoly Nemirko

Nearest Convex Hull Classification uses convex hulls to assign test points to a class based on the point's distances to the convex hulls generated by different classes. The problem is complicated when the test point is in the interior of two or more convex hulls. This can be serious using Euclidean distances since projecting from inside a convex hull is a difficult non-convex problem. We propose a method to locate internal and external test points and approximate distances relative to convex hulls based on linear programming. The advantages over competing approaches is the convenience of LP, the fact that both internal and external test points are processed using the same formulation, and that results are good. We present and discuss the LP formulation and report on results on applications in health care.

4 - **Conjecturing for Automated Discovery of Patterns in Data**
James Brooks, David Edwards, Craig Larson, Nico Van Cleemput

Modern machine learning methods are designed to exploit complex patterns in data regardless of their form, while not necessarily revealing them to the investigator. Here we demonstrate situations where modern machine learning methods are ill-equipped to reveal feature interaction effects and other nonlinear relationships. We propose the use of a conjecturing machine that generates and presents feature relationships in the form of bounds for numerical features and boolean expressions for nominal features. We discuss how the method can be adapted for use in a multi-class classification setting and in a multivariate regression setting.

■ TF-29

Tuesday, 18:30-20:00 - Virtual Room 29

DEA theory and methodological developments

Stream: Data Envelopment Analysis and Performance Measurement
Invited session
Chair: *Juan Aparicio*

1 - **Evaluating Efficiencies of a Set of Decision-Making Units in the Presence of Shared Resources and According to Multiple Grouping Criteria**
Sonia Avilés-Sacoto, Estefania Avilés-Sacoto, Wade Cook, David Güemes-Castorena

Data envelopment analysis (DEA) is a methodology for evaluating efficiencies of a set of decision-making units. Usually it is assumed that these units are independent of one another, so that each has its own set of inputs and outputs. However, there are settings where there can be an interdependence among the units. In a previous paper the authors examine a situation where departments within a university can be grouped according to the set of faculties to which they belong, and share a resource made available at the faculty level. A methodology is developed therein to handle this grouping and sharing phenomenon. The situation becomes more complex when DMUs can be grouped in terms of two or more attributes and share two or more inputs relating to those attributes. The current paper examines a problem setting where there is an interdependence among the decision-making units defined by the multiple grouping criteria. To capture this interdependence, we develop a new DEA-like methodology and apply it to this multiple attribute situation. Further, we present a methodology for evaluating efficiency at the level of the groups, e.g., the level of the faculty, as well as the level of the department.

2 - **Comparison of frontier-based benchmarking methods for efficiency measurement - A Monte Carlo simulation**
Julia Langner, Heinz Ahn, Marcel Clermont

In the last decades, various frontier-based benchmarking methods for measuring efficiency have been developed. However, so far there is only limited knowledge with respect to the question to what extent a certain method is advantageous in different scenarios. We address this issue by a simulation study. In the respective scenarios, nine parameters are varied that reflect the specific structure of the data and knowledge about the competitive environment of the units to be evaluated. In contrast to other studies, we consider, for example, multiple inputs and outputs. Furthermore, in addition to a polypolistic market, we also model markets with a lower competition. The methods compared are Data Envelopment Analysis, Stochastic Frontier Analysis, Stochastic Non-Smooth Envelopment of Data and Normalized Additive Analysis. They are assessed with respect to two purposes of an efficiency measurement: the correctness of the resulting efficiency degrees and the correctness of the resulting ranking. It is shown that depending on the chosen purpose and the scenario, there are large differences regarding the performance of the methods. The results of the study provide a comprehensive basis for the selection between the methods.

3 - **Estimation of production frontiers through Random Forest: the treatment of lack of robustness and curse of dimensionality under Free Disposal Hull**
Juan Aparicio, Miriam Esteve, Jesus J. Rodriguez-Sala, Joe Zhu

In production engineering and microeconomics, an issue of interest is the measurement of technical efficiency of firms. In the literature, there is a plethora of methods for estimating production frontiers through parametric and non-parametric techniques. However, there have been few attempts to approach this problem from the perspective of machine learning, despite currently being one of the methodologies with the greatest repercussion. We aim at filling this gap by adapting Random Forest (Breiman, 2001) to estimate production frontiers and technical efficiency. To do that, we apply decision trees for estimating non-overfitted production possibility sets satisfying free disposability in the context of the Free Disposal Hull (FDH). The main implications of the development of the new approach in this paper is two-fold. First, the derived estimations of technical efficiency are robust to resampling on the data and resampling on the input variables. Second, we show that Random Forest may be also seen as a remedy for the well-known problem of lack of discrimination associated with the FDH approach.

4 - Environmental efficiency measurement when producers control pollutants under heterogeneous conditions: a generalization of the materials balance approach
Andreas Eder

This article provides a generalization of the materials balance-based production model, and the thereof derived environmental efficiency (EE) measure, introduced by Coelli et al. (2007). The Coelli et al. (2007) EE measure produces biased efficiency estimates if the material flow coefficients are heterogeneous across decision-making units and non-discretionary. Furthermore, Coelli et al's EE measure fails to reward emission reductions by emission control. We overcome these shortcomings and provide new EE measures which are decomposed into i) a part reflecting emission control efficiency (ECE), ii) a part measuring material input efficiency (MIE), and iii) a part reflecting the efficient allocation between material and non-material inputs (environmental allocative efficiency, EAE). The approach is illustrated by an empirical application to arable farming in Austria utilizing data from 90 farms. Soil erosion is considered an undesirable output and land a material input. The average EE, ECE, MIE, and EAE are 0.53, 0.96, 0.69, and 0.79, respectively. The results indicate that actual output can be potentially achieved with 47% less soil loss. Most of the potential to improve EE is due to differences in MIE and EAE. Removing inefficiencies in the implementation of existing, subsidized erosion controls allows soil loss to be reduced by 4%.

■ TF-30

Tuesday, 18:30-20:00 - Virtual Room 30

MILP algorithms for graph coloring problems

Stream: Mixed Integer Linear Programming
Invited session
Chair: *Stefano Gualandi*
Chair: *Luca Ferrarini*

1 - New SAT Models & Hybrid Algorithms for Graph Coloring
Matthias Kaul, Stephan Held

We present new SAT formulations for graph coloring. To this end, we adapt symmetry-reducing formulations from integer programming to SAT. They reduce the symmetry and the size of the clauses, which helps to speed-up the SAT computation. Using a state-of-the-art SAT solver, these formulations lead to very fast solution times on several classes of DIMACS instances, in particular the sparse ones.

However, other existing approaches such as branch-and-price, integer programming, or the DSATUR algorithm perform better on other instance classes. To achieve the best of all running times, we present a new implementation running different algorithms in parallel threads. This allows us to exchange lower and in particular upper bounds between the threads to beat the best sequential running times on multiple instances of the DIMACS benchmark set.

Our parallel algorithm performs only safe computations. E.g. we employ integer programming solvers, which could suffer from on floating point inaccuracies, only for upper bounds, while proving optimality in a numerically safe way. Thereby, we can safely exploit the power of integer programming without increasing practical running times on the DIMACS instances.

2 - Graph Coloring with Decision Diagrams
Willem-Jan van Hoeve

We introduce an iterative framework for solving graph coloring problems using decision diagrams. The decision diagram compactly represents all possible color classes, some of which may contain edge conflicts. In each iteration, we use a constrained minimum network flow model to compute a lower bound and identify conflicts. Infeasible color classes associated with these conflicts are removed by refining the decision diagram. We prove that in the best case, our approach may use exponentially smaller diagrams than exact diagrams for proving optimality. We also develop a primal heuristic based on the decision diagram to find a feasible solution at each iteration, as well as a portfolio approach to selecting the best variable ordering. We provide an experimental evaluation on all 137 DIMACS graph coloring instances, and demonstrate that our procedure is competitive with a state-of-the-art graph coloring code based on branch-and-price.

3 - Constraint and Satisfiability Reasoning for Graph Coloring
George Katsirelos

We present some recent work on exact coloring, in which we address the problem by integrating constraint and satisfiability reasoning, based on the addition-contraction recurrence of Zykov. Among other contributions, this approach comprises a new lower bound for this problem based on Mycielskian graphs and novel pruning techniques.

We also show how to scale exact coloring to massive sparse graphs by integrating our exact solver into a core-based solving loop, which works by identifying small subgraphs with potentially large chromatic number. The combination of these approaches allows to improve the best known lower bounds and even close several instances of massive graphs, even when the chromatic number is larger than the clique number.

4 - A Polyhedral Approach to the Total Coloring Problem
Luca Ferrarini, Stefano Gualandi

A Total Coloring of a graph G = (V, E) is an assignment of colors to vertices and edges of G such that neither two adjacent vertices nor two incident edges get the same color, and, for each edge e = v, w, the three elements e, v, w receive a different color. Any valid total coloring induces a partition of the elements of G into total matchings, which are defined as subsets of vertices and edges that can take the same color. The Total Coloring problem generalizes both the Vertex Coloring problem, where we have to color only the vertices of G, and the Edge Coloring problem, where instead we have to color only the edges. In this paper, we formulate the Total Coloring problem as the problem of finding the minimum number of total matchings that cover all the elements of G. We propose an Integer Linear Programming approach based on a column generation algorithm where the pricing subproblem consists of solving a Maximum Weighted Total Matching problem, which generalizes the Matching Problem well-known in the literature. To study the pricing subproblem, we give a polyhedral characterization of the Total Matching Polytope, defined as the convex hull of characteristic vectors of all Total Matchings of G. With this polyhedral approach, we introduce several valid inequalities that are facet-defining. Additionally, we will see how the impact of some important facet-defining inequalities, generated by a separation algorithm, strengths the formulation of the pricing subproblem.

■ TF-31

Tuesday, 18:30-20:00 - Virtual Room 31

Game Theory and Operations Management 2

Stream: Game Theory and Operations Management
Invited session
Chair: *Ana Meca*
Chair: *Alejandro Saavedra-Nieves*

1 - Global Agricultural Supply Chains under Tariff Rate Quotas
Behzad Hezarkhani, Sobhan Asian, Afshin Mansouri

This talk discusses the operational aspects of a common trade mechanism in global agricultural supply chains. A tariff rate quota (TRQ) is a market access instrument that allows a pre-determined quantity of a product to be imported at lower import duty rates (in-quota tariff) than the duty rate normally available for that product (over-quota tariff). Considering the importance of logistical factors in international trade, we investigate the competition among importers who wish to take advantage of the low in-quota tariffs under a first-come, first-served (FCFS) TRQ system. We discuss how the lack of real-time information on quota fill levels and long lead-time affect importers' channel selection and warehousing decisions, which consequently curtails the performance of TRQ systems and results in significant quota-imbalance (i.e., total import quantities exceeding the quota limits). A case study of the EU and the UK imported beef market is presented in conjunction with our model.

2 - Stable Linking of Emission Permit Markets
Greys Sosic

Linking of emission permit markets allows participants in different systems to purchase allowances from each other for the purposes of domestic compliance. As increasing efficiency in reducing carbon emissions is critical for achieving the goals of the Paris Agreement, it is necessary to understand the factors that can impact the stability of linked markets, and what can be done to induce formation of larger and more efficient linked markets. In this paper, we analyze the stable linking of emission permit markets between five jurisdictions: Australia, Canada, the EU, South Korea, and the U.S. Due to asymmetry between different jurisdictions, our results indicate that the most likely stable configuration includes two linked markets: a market that links Australia, the EU, and the U.S., and another in which Canada is linked with South Korea. This scenario leaves about 15% of potential efficiency gains unrealized. To mitigate this issue, we suggest that efficiency gains from market linkage be allocated according to the Shapley value, which takes into account contributions of different jurisdictions to common markets. If the Shapley value allocation is used, our results suggest that we would see stable linking of all five jurisdictions and thus increase the efficiency of market linkage.

3 - On the impact of DMUs on overall efficiency in the event of a merger
Alejandro Saavedra-Nieves, Maria Gloria Fiestras-Janeiro

This talk addresses several mechanisms of overall ranking Decision Making Units (DMUs) according to its contribution to the efficiency of each merger under Data Envelopment Analysis (DEA) with aggregate units. Innovatively, the organization of agents not merging also influences the joint efficiency. This fact requires the usage of games in partition function form and of specific solutions inspired on the Shapley value for ranking DMUs. Their performance is analysed through the theoretical properties that the new class of games satisfies and the computational problems that arise in exactly ranking a large amount of DMUs. As an alternative, we describe a sampling algorithm that reduces these drawbacks. Finally, we apply these proposals to analyse the influence of the efficiency in the tourism industry of the Spanish autonomous communities.

4 - Efficient Effort Equilibrium in Cooperation with Pairwise Cost Reduction
Ana Meca, Jose A. Garcia-martinez, Antonio Jose Mayor-Serra

There is multiple situations in which bilateral interaction of agents results in considerable cost reductions. This pairwise cooperation often requires that the agents involved make a certain level of effort to achieve it. It is natural to think that the amount of cost that one agent could reduce to other agent could depend on the effort that this agent exerts. In the first stage, agents decide how much effort they are to exert, which have a direct impact on their pairwise cost reductions. This stage is modelled as a non-cooperative game, in which agents determine the level of pairwise effort to reduce the cost of their partners. In the second stage, agents participate in a bilateral interaction of independent partners. We study this bilateral cooperation as a cooperative game among agents, in which, as a result of cooperation, agents reduce their cost respectively, so that the total reduction of the cost of each agent in a coalition is the sum of the reductions generated by the rest of the members of that coalition. Based on this model, we explore the costs associated with setting up a pairwise effort network. We identify a family of cost allocations with weighted pairwise reduction, which are always feasible in the cooperative game and contains the Shapley value. We show that there always exist cost allocations with weighted pairwise reduction that generate an optimal level of efficient effort and provide a procedure to find the efficient effort equilibrium.

■ TF-32
Tuesday, 18:30-20:00 - Virtual Room 32

Trade-off between Economics and Environment: the response of cities in the shadow of COVID-19 3

Stream: Multiple Criteria Decision Analysis
Invited session
Chair: *Marta DellOvo*

1 - Smart spaces in smart homes for smart working
Manuela De Ruggiero, Francesca Salvo, Daniela Tavano, Marilena De Simone

Covid 19 pandemic has forced millions of people around the world to work from home. This situation was an emergency at first, but it seems that smart working will be increasingly frequent and lasting in the future. The question we ask is therefore whether working from home can make us healthier, more satisfied and more productive; and how our home design can affect our wellbeing and productivity. Homes are not designed to be workplaces and thermal, visual, acoustic comfort, air quality and ergonomics may be inadequate. It is important to understand how workers perceive their workstation from a mental and health point of view and what are the most critical aspects in order to identify ergonomic and comfortable architectural solutions. It will be necessary to adapt homes to workstations and this will require intellectual effort and of course associated costs. The present work aims to evaluate how these new dimensions of living and working affect the value of real estate assets, first investigating the costs associated with the adaptation of spaces through the tools offered by the Cost Approach, and subsequently evaluating the economic effects in terms of value of the spaces. Because we have not yet market data capable of representing the real appreciation of real estate users with respect to a set of new real estate variables, the appraisal analysis is based on virtual market simulation, through Contingent Valuation.

2 - Analysis of market behaviors in residential property choices: a methodological approach for assessing buyers' preferences in the Italian context
Felicia Di Liddo, Pierluigi Morano, Francesco Tajani, Marco Locurcio, Paola Amoruso

In the context of the measures adopted by the Governments for the containment of the COVID-19 pandemic, the lockdown period has led to change daily lifestyles and working habits. The present research aims to define a methodological approach to analyze the Italian residential market behavior, in terms of real estate dynamics that link the selling prices and the preferences expressed by potential buyers in the choice phases, With reference to all the Italian municipalities and to the data collected by the National Statistics Institute (ISTAT), the study intends to examine the functional correlations between the average residential property prices and the main architectural (mean buildings age, construction technique, building maintenance conditions, etc.), social (population, education level, mean population age, etc.) and territorial (seismic and climatic zone in which each municipality is located) variables. The implementation of a multi-objective evolutionary genetic algorithm has allowed the determination of the price function able to simultaneously pursue different objective functions, such as to define an optimal Pareto frontier of fixed conflictual objectives. The work is part of a wider research to be developed. In this regard, the analysis intends to compare the outputs of this first step with those deriving from the implementations on the ISTAT 2021 census data, to identify and evaluate likely changes in the housing market demand.

3 - MCDA to support post-pandemic strategies for cultural heritage in marginal areas: evidences from an inner area in Campania Region
Marco Rossitti, Francesca Torrieri

The Covid-19 pandemic has led to a forced reflection about the leading urbanization model and to greater attention towards marginal areas. In Italy, in particular, the scientific and media debate has focused on inner areas, that since 2014 have represented the target of an innovative national cohesion policy aimed at tackling their depopulation: the National Strategy for Inner Areas (SNAI). Indeed, Italian inner areas are endowed with an extraordinary natural capital and are based on settlement models far from urban density. Thus, they seem to be a perfect response to the new raised living needs. However, leaving aside the optimistic rhetoric, strong political and administrative choices are necessary to trigger a 'return process', based on this wider attention towards inner areas, thus countering the mankind's natural tendence to concentrate in urban realities. In this light, the contribution proposes a MCDA tool to support SNAI in designing and implementing local development strategies, based on the conservation and enhancement of its under-used architectural heritage. After a critical reading of the new challenges for planning posed by the pandemic and SNAI's role within them, the contribution moves to frame the decision support tool, focusing on specificities of the inner areas. Finally, the tool's application to a case study, an inner area in Campania Region, allows to outline and discuss its possible benefits to SNAI implementation and its limits.

■ TF-33

Tuesday, 18:30-20:00 - Virtual Room 33

New frontiers in asset pricing

Stream: New challenges for financial modelling
Invited session
Chair: *Roy Cerqueti*
Chair: *Mario Maggi*

1 - The Determinants of Minibonds in the Italian Market
Saverio Storani, Roy Cerqueti, Catherine Deffains-Crapsky, Anna Grazia Quaranta

This article investigates those companies that, following the financial crisis, have resorted to a new financial instrument introduced by national governments through specific regulations. In particular, the Italian market is considered. Our empirical article analyzes which are the determining factors that push a company to issue high quantities of minibonds. Our analysis is of the cross-sectional type and includes a plurality of independent variables provided by an extensive literature review. We also use two main dependent variables, namely the ratio between the amount of minibonds issued with respect to total debts and total assets. A focus will also be on the nature of the debt. Our main empirical results show that small and medium- sized enterprises make greater use of this alternative financing tool than large enterprises. As well as those companies with high cash flows and which are subject to low risk. A less obvious significance was the differential between bank rates. A negative relationship is found for the leverage and total asset variables.

2 - Asset allocation determinants under different decision models
Mario Maggi

This paper proposes a comparison in terms of asset allocation results of Cumulative Prospect Theory, Prospect Theory and Expected Utility. The various decision rules are first applied to an artificial financial market, where the returns are generated in order to be endowed with the desired features, in terms of mean, variance, skewness, kurtosis and correlation. This allows to detect the effects of the first four moments of the return distribution on asset allocation, in different decision maker models. A final application to real data is also presented.

3 - An Optimal Market Making Model where the Price Dynamics Follows a Mean-reverting Process with Stochastic Volatility
Burcu Aydogan, Ömür Ugur, Ümit Aksoy

In this study, we intend to develop optimal market making strategies for high-frequency trading in a limit order book where the stock price is generated by a mean-reverting process with stochastic volatility. In this model, we further assume that the price changes with the adverse selection effects including the jump components. We suppose that the trader is risk-neutral and the objective function of the trader is to maximize her terminal wealth with a control of the inventories. Our aim is to get the optimal bid and ask prices by these assumptions and modelling. For this purpose, we write the corresponding Hamilton-Jacobi-Bellman (HJB) equation of the stochastic control problem. Then, we reduce the HJB equation in a PDE system which gives us the optimal prices. The PDE system is solved by applying the finite difference method and linear interpolation and extrapolation techniques. Then, we provide our numerical illustrations and optimal behaviours of the trader with this stock price modelling.

4 - How Do Investors Prefer Banks to Transit to Basel Internal Models: Mandatorily or Voluntarily?
Henry Penikas, Anastasia Skarednova, Mikhail Surkov

The recently finalized Basel Framework continues allowing banks to use internal data and models to define risk estimates and use them for the capital adequacy ratio computation. World-wide there are above two thousand banks running the Basel internal models. However, there are countries that have none of such banks. For them there exists a dilemma. Namely, which transition path to adopt out of the two. The voluntarily one as in the EU or the mandatory one as in the US. Our objective is to take the investor perspective and benchmark those two modes. Thus, we wish to find whether there is a premium for any of them, or perhaps that they are equivalent. The novelty of our research is the robust estimate that investors prefer mandatory transition style to the voluntarily one. However, we should be cautious in interpreting our findings. Such a preference may not only be the premium for the breakage of the vicious cycle and the ultimate improvement in the banks' risk-management systems and the overall financial stability. It may also hold true if and only if the mandatory transition for particular institutions is accompanied by a restriction for other banks in the region to transit. Our findings are of value primarily to the emerging economies like Argentine and Indonesia.

■ TF-34

Tuesday, 18:30-20:00 - Virtual Room 34

Optimization Advances with Quantum Applications II

Stream: Combinatorial Optimization
Invited session
Chair: *Fred Glover*
Chair: *Gary Kochenberger*
Chair: *Yu Du*

1 - Optimisation and reconfiguration of 5G network slicing
Hanane Biallach, Mustapha Bouhtou, Dritan Nace, Sofiane Imadali

The explosive growth of devices and the increasing diversity applications create a large variety of needs. The 5G network slicing is arrived to provide flexibility in the network and performance characteristics tailored to this different needs. One challenge associated with these requirements is the reconfiguration of 5G network slicing problem, which occurs due to different dynamic slicing operations that impact the performance of other slices and make the placement of old slice resources inefficient. Our objective is to schedule different slices and generate a reconfiguration plan to pass efficiently from an initial state where slices are not optimally allocated toward a new optimal state while minimizing the service interruption. This problem is NP-Hard and to deal with it, we proposed Mixed Integer Linear Programming model that takes into account both of hot and cold migration. Furthermore, we formulated the problem as a graph one. The vertices represent the servers and the arcs represent the migrations of the Virtualized Network Functions (VNFs) which constitute each slice. If the resulting graph is acyclic, the solution is feasible in polynomial time. If the graph is cyclic, one may apply the feedback arc set problem algorithm to render it acyclic. Then we apply the topological sorting to obtain the reconfiguration plan that contains the list of VNF migrations. Both solutions are tested on synthetic datasets for validation.

2 - Quantum-inspired formulations for the max k-cut problem
Ramin Fakhimi, Hamidreza Validi, Illya Hicks, Tamás Terlaky, Luis Zuluaga

Solving combinatorial optimization problems on quantum computers has attracted many researchers since the emergence of quantum computing. The max k-cut problem is a challenging combinatorial optimization problem with multiple optimization formulations, including two mixed-integer linear optimization (MILO) formulations and a semidefinite optimization (SDO) formulation time-consuming to be solved. Motivated by shortcomings of the MILO and SDO formulations, we study a binary quadratic optimization (BQO) formulation and compare it with two classic $milo$ formulations. Further, we propose an algorithm that converts any feasible fractional solution of the BQO formulation to a feasible binary solution whose objective value is at least as good as that of the fractional solution. Finally, inspired by the application of binary quadratic formulations in the burgeoning area of quantum computing, we propose new quadratic unconstrained binary optimization formulations.

3 - Constraint Programming to Discover One-Flip Local Optima of Quadratic Unconstrained Binary Optimization Problems
Amit Verma, Mark Lewis

The Quadratic Unconstrained Binary Optimization (QUBO) modeling format is a general-purpose modeling framework and a requirement for some gate array and quantum annealing computers. QUBO annealers, as well as other solution approaches, benefit from starting with a diverse set of elite solutions. For example, path relinking is a powerful tool benefitting from elite, diverse solutions. We present a new method for generating an elite set of one-flip local optima that leverages constraint programming where the outputs could be utilized as starting solutions or for the construction of local optima networks. We also describe and implement a learning-based technique using soft constraints modifying the linear coefficients of the Q matrix in order to affect the search to either favor or avoid one-flip local optima.

■ TF-35

Tuesday, 18:30-20:00 - Virtual Room 35

OR and Analytics Education

Stream: OR Education Initiatives
Invited session
Chair: *Maria Antónia Carravilla*
Chair: *José Fernando Oliveira*

1 - Use of LaModAl in an undergraduate Operations Research course: a case study
Davi Doro, Ricardo Camargo

IDE's (Integrated Development Environments) are tools used by programmers and modelers to develop and run their programs. With the advent of the Internet, many of them have been moving from the desktop to the web, giving rise to Web IDE's (WIDE's). In this category of web applications, to the best of our knowledge, there are only two WIDE's aimed specifically at the development of optimization models, namely Watson Studio and RASON IDE. Now a third one, named LaModAl (lamodal.com), emerges as an alternative for the operations research community. LaModAl differs from the alternatives by i) its support of the AMPL modeling language, ii) its real-time collaborative editor and iii) its remote solver execution solution. These features make LaModAl well suited for being used as an aiding tool on operations research courses, especially during quarantine. Here, we present a case study which assessed how 18 students taking an introductory course on operations research perceived LaModAl after having used it for one academic semester in 2020. We highlight the following results: 1) most of the students thought that the interface was clear and easy to use, 2) LaModAl has facilitated their learning experience, 3) the collaborative editing feature was important for the group assignments and 4) all the students would recommend LaModAl for their colleagues. We hope that these results will encourage other students around the world to benefit from the use of LaModAl as well.

2 - On Effects of Non-Cognitive Skills in Late Childhood on School Performance in Italy
Ekaterina Skatova, Maria De Paola

On Effects of Non-Cognitive Skills in Late Childhood on School Performance in Italy Ekaterina Skatova*, Maria De Paola*'

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Since studies on non-cognitive skills become more and more important in economics of education (see [1,2]), we investigate whether students' non-cognitive skills affect their educational outcomes using a very rich panel dataset from the Italian National Institute for the Evaluation of the System of Education and Training. It provides information for a cohort of Italian students on school performance, demographic characteristics, and on a number of personal traits. For these pupils we estimate how test scores in literacy and numeracy obtained in 8th grade were affected by their non-cognitive skills as measured when attending primary school, controlling for their ex-ante cognitive abilities as proxied by tests scores achieved in 5th grade.

References

1. Checchi, D., De Paola, M. 2018. The effect of multigrade classes on cognitive and non- cognitive skills. Causal evidence exploiting minimum class size rules in Italy. Economics of Education Review, 67, 235-253. 2. Humphries J. E., Kosse, F. 2017. On the interpretation of non-cognitive skills-What is being measured and why it matters. Journal of Economic Behavior & Organization, 136, 174-185.

3 - Data Governance Implementation Using Full Stack BI Tool
Olga Nazarenko

Development of Business Intelligence solutions aiming to support decision-making. However, the real business benefit appears when an insight actionable ecosystem is built inside the company. We would like to share the results of data governance assessment and development inside the company, our approaches for data culture growth, and data citizenship idea implementation. The technological stack of the project was limited to a single full-stack cloud BI system, however different tools for communication and stakeholders aligning were used.

■ TF-36

Tuesday, 18:30-20:00 - Virtual Room 36

Credit Risk Management

Stream: Risk management in Finance
Invited session
Chair: *Davide Radi*
Chair: *Andrea Perchiazzo*

1 - A hybrid credit-risk model with stochastic recovery rate
Davide Radi, Graziella Pacelli, Luca Vincenzo Ballestra

In this paper we propose a hybrid credit risk model with stochastic recovery rate. Default occurs either the first time a default barrier is breached from above by a credit-quality signaling variable or at the first jump of a counting process. The credit-quality signaling variable follows a geometric Brownian motion while the default intensity of the counting process depends on the risk-free interest rate. The risk-free interest rate is assumed to be stochastic. At default, the recovery rate is assumed to be a non-decreasing function of the credit-quality signaling variable. We derive a closed-form formula for pricing the spreads of credit default swaps (CDSs). An empirical investigation that involves European companies shows that the stochastic nature of the recovery rate increases the goodness-of-fit of the model.

2 - Financial contagion in banking networks with community structure
Gabriele Torri, Rosella Giacometti

Monitoring and controlling financial contagion in banking systems is a challenging task, and microstructural contagion models are becoming fundamental policy tools for supervisors. A large body of literature studies the theoretical properties of the diffusion of financial shocks in banking networks, measuring the spread of shocks in relationship to the structural properties of the network. A property that is not extensively studied in the financial networks literature is the presence of network community structures. That is, the presence of groups of banks that are strongly connected among each other. In the European context, such communities may be related to country divisions, as a result of the progressive integration of national banking systems. Here we study how the diffusion of liquidity shocks in a simulated banking systems is affected by the presence of a community structure. We find that communities highly affects contagion, increasing the amount of distress transmitted and the number of banks involved. The results is robust across a broad range of network specifications. We also test the potential effects on contagion risk of stylized policies: the introduction of higher liquidity requirements, the definition of liquidity requirements based on network indicators, and the modification of confidence in the market by individual banks. Results can be of interest for regulators willing to study the diffusion of liquidity risk and to set up macro-prudential policies.

3 - Empirical Asset Pricing: Economic Significance and Economic Model Evaluation
Bernhard Nietert, Thomas Otto

Empirical models consist of two components: factors and statistical methods. The choice of factors has been extensively analyzed in the literature, motivating Harvey/Liu (2019) and the American Statistical Society (2016) to complain about a "factor zoo": The literature just chooses factors to bring up the p-value, but not because these factors might be economically useful.—Luckily, there exists a solution to this problem: model nesting of Barillas/Shanken (2018). With respect to statistical methods we are nowadays confronted with a "model zoo", i.e., are caught in similar situation as we were 10 years ago with factors. However, we do not have the statistical criterion of Barillas/Shanken (2018) to help us dealing with the "model zoo". In fact, statistical criteria might not even be helpful in this connection. For that reason, this paper, first, shows empirically that different statistical methods translate into economically significant valuation differences. Therefore, a criterion is needed that can evaluate statistical methods from an economic perspective. Second, such a criterion is derived using Lagrange duality and it is shown: Quantile regression proves to be the best statistical method from an economic perspective because it is able to offer a good approximation to the economic principle and mimics best institutional circumstances. Statistically more advanced methods like generalized least squares regression possess an inferior economic interpretation.

4 - Implied Value-at-Risk and Model-Free Simulation
Andrea Perchiazzo, Carole Bernard, Steven Vanduffel

We propose a novel model-free approach for extracting the risk-neutral quantile function of an asset using option prices. We develop two applications. First, we show that the asset's implied Value-at-Risk and Tail Value-at-Risk can be directly estimated using the options that are written on it. Second, we show how for a given stochastic asset model our approach makes it possible to simulate the underlying terminal asset value in a direct manner. Specifically, it is shown that our approach outperforms existing approaches for simulating asset values for stochastic volatility models such as the Heston and the SABR models.

■ TF-37

Tuesday, 18:30-20:00 - Virtual Room 37

Modelling the value of medicines, vaccines and social interventions to tackle infectious diseases 1

Stream: Ethics in OR
Invited session
Chair: *Abigail Colson*

1 - Spread of covid-19 via staff working across different care homes: a hybrid simulation model
Le Khanh Ngan Nguyen, Itamar Megiddo, Susan Howick

Evidence on the increasing risk of SARS-CoV-2 infection in staff working across different care homes has emerged. As a result, new regulations proposed by the UK Government would ban staff from moving between care homes in an attempt to halt the spread of COVID-19. These types of interventions need to be thought through as they may lead to unintended consequences and they need to be balanced against outcomes that are not related to Covid-19. Care homes in the UK are heavily dependent on the use of agency or bank staff due to the long-standing problem of staff shortages in the health and social care sector, which has been worse amid the pandemic. Understaffed care homes could lead to lower quality of care for residents, and a lower staff-to-patient ratio can also increase transmission within care homes. There is limited understanding of the extent to which staff working in multiple care homes contribute to spreading the infection and which interventions targeting this group are effective. To address these issues, we have developed a hybrid simulation model that combines system dynamics and agent-based modelling methods to represent staff sharing in a network of care homes. The evaluated interventions in controlling the spread of COVID-19 across care homes include creating bubbles of care homes, routine testing of agency and bank staff, and ceasing agency and bank staff use.

2 - A visual approach to the Economic Evaluation of vaccines: opening the health economic black box
Alec Morton, Enoch Kung, Vittoria Bufali

Objectives: The economic evaluation of vaccines has attracted a great deal of controversy. In the academic literature, several vaccination advocates argue that the evaluation frame for vaccines should be expanded to give a more complete picture of their benefits. We seek to contribute to the debate and facilitate informed dialogue about vaccine assessment using visualization, as able to support both deliberation by technical committees about the substance of evaluation and communication of the underlying rationale to non-expert stakeholders. Methods: We present two visualizations, an Individual Risk Plot (IRP) and a Population Impact Plot (PIP), both showing the beneficiary population on one axis and the degree of individual benefit and cost of an individual dose on the second axis. We sketch out such graphs for ten vaccines belonging to the UK routine childhood immunization schedule, and present our own analysis for the rotavirus and meningitis B vaccines. Results: While the IRPs help classify diseases by morbidity and mortality, the PIPs display the health and economic loss averted after introducing a vaccine, allowing further comparisons. Conclusions: The visualizations presented, albeit open to provide an increasingly complete accounting of the value of vaccination, ensure consistency of approach where comparative judgements are most needed.

3 - Agent-based modelling to explore Covid-19 interventions in a care home
Itamar Megiddo, Le Khanh Ngan Nguyen, Susan Howick, Robert van der Meer

Care homes have suffered an extremely high burden of disease form Covid-19, with over 40% of 2020 Covid-19 deaths attributed to care homes in many countries, including the UK and US. Plenty of research has been done on how to control infection outbreaks in hospital environments over the past couple of decades; however, research on what works in care homes has been very limited. Care homes are unique in that they act as a home in addition to a health facility, and imposing guidelines from the hospital setting is not practical. We explore what interventions work best within a single care home (interacting with its surrounding community), using an agent-based model that was developed in collaboration with colleagues working in care homes. Agents in the model include care home staff and residents. We explore interventions of personal protective equipment and hand hygiene, resident and staff testing and their frequency, cohorting of residents units, and limiting guest visiting along with the implications of the beginning of the vaccination campaign.

■ TF-38

Tuesday, 18:30-20:00 - Virtual Room 38

Health-care resource planning during pandemics and disasters

Stream: Humanitarian Operations
Invited session
Chair: *Burcu Balcik*
Chair: *Evrim Didem Gunes*

1 - A Resource Planning Model for Effective Management of Chronic Patients After Disasters
Cem Deniz Caglar Bozkir, Burcu Balcik, Evrim Didem Gunes

Chronic dialysis patients must visit health care facilities (hospitals, private dialysis centers) to receive hemodialysis treatments regularly (three times a week). After a severe disaster, these patients may miss their dialysis sessions due to reduced dialysis capacity. We focus on a post-disaster health care planning problem, which assigns chronic dialysis patients to the available sessions at the functioning health care facilities by considering different treatment choices and accessibility of services. We develop an integer programming model and alternative solution methods. We illustrate our approaches based on a case study.

2 - Capacity Planning for Effective Cohorting of Dialysis Patients during the Coronavirus Pandemic: A Case Study
Cagri Ozmemis, Burcu Balcik, Cem Deniz Caglar Bozkir, Evrim Didem Gunes, Ali Kaan Kurbanzade

Chronic dialysis patients have been among the most vulnerable groups of the society during the coronavirus pandemic as they need regular treatments in a hospital environment, facing infection risk. Motivated by the operations of a hemodialysis clinic, we address capacity planning decisions to apply a three-unit cohorting strategy to mitigate infection spread risk among patients by treating infected, suspected and uninfected patients in separate units and at different times. We represent the uncertainties in the number of patients by a set of scenarios and develop a two-stage stochastic programming approach to make capacity planning decisions. We present a case study to illustrate the effectiveness of the proposed model and compare the performance of different cohorting strategies.

3 - A Large Neighbourhood Search Metaheuristic for the Contagious Disease Testing Problem
David Wolfinger, Margaretha Gansterer, Karl Doerner, Nikolas Popper

In late 2019 a new coronavirus disease (COVID-19) emerged, causing a global pandemic within only a few weeks. A crucial factor in the public health response to pandemics is achieving a short turnaround time between a potential case becoming known, specimen collection and availability of a test result. We address a logistics problem that arises in the context of testing potential cases. We assume that specimens can be collected in two ways: either by means of a mobile test-team or by means of a stationary test-team in a so called (drive-in) test-centre. After the specimens have been collected they must be delivered to a laboratory in order to be analysed. The problem we address aims at deciding how many test-centres to open and where, how many mobile test-teams to use, which suspected cases to assign to a test-centre and which to visit with a mobile test-team, which specimen to assign to which laboratory, and planning the routes of the mobile test-teams. The objective is to minimise the total cost of opening test-centres and routing mobile test-teams.

We introduce this new problem, which we call the Contagious Disease Testing Problem, and propose a large neighbourhood search metaheuristic for solving it. Furthermore, we give managerial insights regarding COVID-19 test logistics, derived from problem instances based on real world data.

4 - An ILP approach to medical resource allocation after mass-casualty incidents and evaluation of disaster simulation exercises
Patricia Rogetzer, Gelbrich Holsbrink, Derya Demirtas, Nancy ter Bogt

During a mass-casualty incident (MCI), treatment capabilities of the regional hospitals are overwhelmed. In the Netherlands, emergency care networks prepare their regions for an MCI by organizing analog simulation exercises called Emergo Train System (ETS) exercises. In 2019, two separate emergency medical teams simulated the allocation process of casualties to ambulances and hospitals during an MCI using ETS. The results differed significantly between the teams. Although the ETS exercises are used worldwide, the optimal solutions are not known. In this research, we propose an Integer Linear Programming (ILP) model that allocates each casualty of an MCI to an ambulance and a hospital. We demonstrate the effectiveness of our model by comparing its results to the performance measures of the ETS exercises from 2019 and providing sensitivity analyses.

■ TF-39

Tuesday, 18:30-20:00 - Virtual Room 39

Pickup and delivery problems

Stream: Routing, Logistics, Location and Freight Transportation
Invited session
Chair: *Yannis (Ioannis) Marinakis*

1 - Real-application of order assignment and route planning
Jan Sporkmann, Stefan Spinler, Christian Kloimüllner

Our order assignment and route planning problem belongs to the family of pickup and delivery problems (PDP). It offers an advanced solution to a real-world application - motivated by a project for a German logistics company. Taking into consideration some practical complexities (e.g., time window constraints, multi-dimensional capacity constraints), our approach aims for maximizing the number of requests assigned to available vehicles. For each vehicle, a minimum revenue must be generated in total from all assigned requests. In this research, we present a mathematical formulation and a construction heuristic to initially solve the problem based on real-world empirical data.

2 - A Hybrid Model Applied to the Vehicles Routing Problem With Simultaneous Pickups and Deliveries - VRP-SPD.
Pedro Pablo Ballesteros Silva

Since many decades ago, one of the topics of greatest interest in research is that one related to the vehicle routing problem, present in many organizations. This, which is a transport problem, has multiple implications of economic, social, technological, and environmental order, when there is a provision of services to customers in the development and implementation of production processes, in the provisioning and distribution of goods and services, including carrying people within a determined time frame, with an adequate quality level. This paper presents a methodology to solve the homogeneous vehicles routing problem with simultaneous pickups and deliveries (VRPSPD) using matheuristics formed by the specialized genetic algorithm's Chu-Beasley and exact techniques of mixed integer linear programming, based on the Branch-and-Bound procedure. The VRPSPD problem considers a set of customers, whose demands of pick-up and delivery of products or people are known, and whose objective is to get the set of routes of minimal cost, which allow to satisfy the demand of the customers, considering the respective constraints of the system and the vehicles necessary for the completion of the same. Two new algorithms designed by the authors are implemented, which have been coded in C ++, obtaining good results in relatively short computing times, depending on the characteristics of the computers used.

3 - A special case of the Vehicle Routing Problem with pickup and time windows: A case study of raw milk transportation in Tunisia
Chaima Ben Abdallah, Adnen El Amraoui, François Delmotte, Ahmed Frikha

The research work presented here describes an integrated method to solve a clustered vehicle-routing problem (CVRP) of perishable product to handle the milk collection process with the minimum distance travelled and maximum loading. The proposed approach is a two-step method. The first step consists of locating tanks that allow producers to store their milk daily. Cluster centers are created to optimize the milk collection problem by considering the seasonality of production. Dynamic clustering algorithm with cluster capacity constraints is developed to divide farmers into clusters and assign each producer to one cluster. Clustering before solving the vehicle routing problem is an essential step in our solving methodology because it drastically reduced the problem complexity. Then, in the second step, and once the network has been designed, an integer linear programming model is elaborated to optimize the collection activity and where the perishability characteristic of the agro-food product is considered. The developed approach has been validated on real case study and the obtained results showed its effectiveness.

4 - Urban logistics: modern problems require modern solutions.
Yannis (Ioannis) Marinakis, Themistoklis Stamadianos, Magdalene Marinaki, Nikolaos Matsatsinis

The outbreak of COVID-19 has had a ubiquitous impact both in personal and professional affairs. Government mandated lockdowns are the new norm, and everyone must conform. One of the actions to contain the spread of the virus has been the adoption of policies to strictly enforce transportation limits for citizens, along with the mandated closure of businesses deemed non-essential by governments. This led to a rapid increase of e-commerce activities to fill the void, while urban logistics saw a rise in popularity. Numerous businesses started offering door-to-door deliveries, often giving the option for contactless deliveries, including grocery stores. These actions have affected the supply chain, unbalancing their load, exceeding their delivering capacity, and being forced to deny services for certain time periods. These circumstances call for new support frameworks to enhance the delivering capacity of carriers in urban scenarios, through clever planning while providing the ability to adapt to an everchanging environment. A system was developed to assist in pickup and delivery planning, well suited for large cities. A variety of solutions is provided for each problem and a mechanism was put in place to present the solution closest to the needs of the decision maker. All the above have been united under a single Decision Support System.

■ TF-40

Tuesday, 18:30-20:00 - Virtual Room 40

Workforce Scheduling and Line Balancing 2

Stream: Scheduling and Project Management
Invited session
Chair: *Alexander Benavides*

1 - A bi-objective branch-and-bound for the assembly balancing line integrating fatigue and recovery of the operators
Audrey Cerqueus, Xavier Delorme, Mohammed-Amine Abdous

Ergonomics is a growing concerned in production systems. Companies aim to reduce work-related illnesses and the induced expenses (absenteeism, occupational accidents,...). The working conditions are mostly determined by the production system design, so this objective must be included early in the system design. The assignment of the tasks to the workstations plays a key role for ergonomics. The simple assembly line balancing problem (SALBP) is both one of the simplest and one of the most studied variants of this problem.

In this work, we propose a solution method for the SALBP, introduced in [1], considering two objectives. The first one is related to the cost (by the number of stations) and the other is an ergonomic measure of the fatigue and recovery of operators. This last objective is based on the idea that the fatigue of the operator at the end of a cycle depends on the duration and difficulty of the tasks executed and on the recovery time. The method is an extension of the work presented in [2], integrating the ergonomic objective which is non-linear.

Experimental results compare the performance of the bi-objective branch-and-bound to an epsilon-constraint.

[1] M.-A. Abdous, X. Delorme, D. Battini, F. Sgarbossa, S. Berger-Douce, Assembly line balancing problem with consideration of workers fatigue and recovery, IWSPE, 2018 [2] A. Cerqueus, X. Delorme, A branch-and-bound method for the bi-objective simple line assembly balancing problem, IJPR, 57(18), 2019

2 - Balancing multi-model assembly lines in a reconfigurable environment
David Tremblet, Abdelkrim R. Yelles-Chaouche, Evgeny Gurevsky, Nadjib Brahimi, Alexandre Dolgui

The present communication deals with multi-model assembly lines, which are able to handle several products from a same family. Each product is characterized by the same set of tasks to be performed on a given number of workstations. However, the task processing time, precedence and cycle time constraints may be different from one product to another. Balancing such a line consists in designing an admissible line configuration for each product by assigning the corresponding set of tasks to the workstations while satisfying the aforementioned constraints. The products of the same type are executed sequentially in batches. Thus, when a new product type needs to be produced, the line should be reconfigured accordingly by reassigning some tasks. For the studied problem, it is supposed that the order of product type arrival is not known in advance. As a result, a natural way in this situation is to balance such a line so as the maximum number of task reassignments between any two line configurations is minimized.

To tackle this problem, a MILP model is initially proposed. Then, a MILP-based approximate approach, named as halt-and-fix heuristic, is developed in order to deal efficiently with large size instances. The obtained preliminary computational results show that the performance of the approximate approach is very promising. The implementation of the proposed heuristic as well as its comparison with the MILP model will be reported during the presentation.

3 - A constraint programming model for flow shop scheduling with heterogeneous workers
Alexander Benavides

The heterogeneous flow shop scheduling problem (Het-FSSP) is composed of two subproblems that must be solved together: the assignment of workers with different capabilites to workstation machines, and the scheduling of jobs in that flow shop. This environment is inspired in sheltered work-centers for disabled where workers show different capabilites, i.e., the processing time for each job on each machine depends on the worker assigned to that machine. To reach a high productivity in such environment, the objective function of the Het-FSSP is the minimization of the makespan. When we proposed the Het-FSSP (Benavides et al., 2014; doi:10.1016/j.ejor.2014.02.012), we also defined it mathematically with a mixed-integer linear programming (MILP) model. Here, we propose a constraint programming (CP) model for the Het-FSSP and we compare the performance of both models. Our computational results show that the CP model produces better solutions than the MILP model. Furthermore, the CP model produces solutions for all the tested instances while the MILP model does not. Future research includes comparing CP models and MILP models that consider only permutational schedules against models that allow non-permutational schedules.

■ TF-41

Tuesday, 18:30-20:00 - Virtual Room 41

Supply chain strategy II

Stream: Production and logistics and revenue management (contributed)
Contributed session
Chair: *Masoumeh Kazemi Zanjani*
Chair: *Hoora Katoozian*

1 - An Empirical Analysis Between Industry 4.0 Scores and Occurrence Frequency of Lean Wastes for Turkish SMEs
Oğuz Emir, Uğurcan Dündar, Zeynep Gergin, Fadime Üney-Yüksektepe

Focusing on cost, quality, and time management should always be on the agenda of the enterprises to survive in the global market due to the rapidly changing customer preferences, technology, information, and material concepts. Due to these changes and needs in the competitive field, Lean manufacturing has been emerged to eliminate all wastes and pursue continuous improvement. Recently, the notion of Industry 4.0 has emerged in 2011 and its importance has gradually increased with the integration of novel technologies. In 2018, an in-depth study is started to identify the current situation of Industry 4.0 for Turkish Small and Medium-Sized Enterprises (SMEs). For this purpose, a comprehensive questionnaire is designed that consists of 28 questions to measure the industrialization level of SMEs taking into account different aspects from the number of employees to the occurrence frequency of wastes. Following the completion of the questionnaire, an industrialization level is assigned ranging from 1.0 to 4.0 based on all industrial revolutions' perspectives. This paper investigates the relationship between the Industry 4.0 score of SMEs and the occurrence frequency of lean management's seven wastes. In this order, a hypothesis testing approach is deployed with the responses gathered by questionnaire. The formed hypothesis is tested with Chi-square test for association and the results have shown that the relation between these two concepts is considerably significant.

2 - Multi-period Outsourcing Decision in the Presence of Supplier Copycatting
Shobeir Amirnequiee, Hubert Pun, Joe Naoum-Sawaya

Counterfeits and pirated goods pose an unprecedented threat to the businesses worldwide. The problem has intensified to staggering levels over the recent years. A common form of counterfeiting is what investigators call the "ghost shift," which happens when firms outsource their production to the suppliers overseas, and the suppliers activate a third shift to produce a counterfeit product using the firm's intellectual property. In this paper, we develop a multi-period, probabilistic game to model the relationship between an outsourcing manufacturer and two types of suppliers: a low-quality supplier and a high-quality copycat supplier. Specifically, we study the manufacturer's optimal strategy when future outsourcing opportunities exist and the copycat supplier's optimal strategy when encroaching to the market has future repercussions. We find that (1.) the optimal strategies for both the manufacturer and the copycat supplier are radically different when future opportunities and future repercussions exist, (2.) the manufacturer's brand quality can both harm and improve the high-quality copycat supplier and the low-quality supplier's profit, (3.) the low-quality supplier can be worse off at a higher level of quality, and (4.) the manufacturer can benefit from a lower brand quality.

3 - How Stagger Charts Can improve Forecast Accuracy
Agneta Ramosaj, Marino Widmer

Demand forecasting helps to take the right decisions at every enterprise's level and allows procurement decisions in terms of production. A way to depict them is provided by a stagger chart, a visual tool easy to implement and to understand, useful for displaying forecasts and forecast errors. The forecast added value (FVA), combined with the stagger chart, shows the reduction's percentage of the forcasts errors. In this talk, the role of stagger charts in forecasting is described and the tool is extended into pivot tables that display multiple views of the business. Further, a case study illustrates the use of stagger chart in a small to medium enterprise (SME). The goal is to show how a SME applies these tools to improve its forecasting performance. The sales predictions of this SME are also analyzed; the results of quantitative and qualitative forecasting methods are compared thanks to a stagger chart. Quantitative methods provide better forecasts than qualitative ones and the combination of those methods with the stagger chart helps the SME to improve drastically its forecasts'accuracy and to decrease significantly its forecasting errors.

4 - Industry 4.0 Supply Network Design for Mass Personalization
Hoora Katoozian, Masoumeh Kazemi Zanjani

Align with the paradigm shift to the forth industrial revolution, the manufacturing industry is confronted with the growing demand of personalized products of small batch sizes. In other words, the producers are faced with the satisfaction of heterogeneous customer needs through individualization and the realization of scale effects along the value chain. The aforementioned complexities call for the reconfigurability of the manufacturing network. This study is among the first proposing a mixed-integer programming model that aims to obtain the optimal configuration of a supply network comprising of a pool of component suppliers and sub-assembly manufacturers in order to satisfy the demand of highly-customized and modular-structured products. The goal is to maximize the profit and service level, measured as the quantity of lost sale. While the product individualization is incorporated into the model by considering different design complexity levels for the components/sub-assemblies involved in the bill-of-material, the impact of production scale is modeled by considering piece-wise production cost functions. We conduct an extensive set of numerical experiments inspired by the case of tunable lasers that are featured with several customization options. Our numerical results indicate that the configuration of supply network drastically varies as a function of the demand at different design complexity levels as well as the suppliers' cost structure.

■ TF-42

Tuesday, 18:30-20:00 - Virtual Room 42

Web Content and Behaviour

Stream: Modelling and Simulation of Social-Behavioural Phenomena in Creative Societies
Invited session
Chair: *Mustafa Alassad*

1 - A socio-technical framework for measuring connective action in online social networks
Billy Spann, Nitin Agarwal

This research proposes a conceptual framework to measure connective action in online social networks (OSNs). We extend social science research on connective action theory by proposing a mixed-method computational approach to examine the affordances and features offered through OSNs. Our framework is based on three key connective action principles: (1) collective identity formation; (2) network organization; and (3) mobilization. The principles are tied together by applying social network analysis techniques to measure modularity, community detection, and centrality methods to reveal the organizational components and affordances. Topic analysis using NLP is performed to identify shared interests within communities. To evaluate our framework, we present a comprehensive analysis of COVID-19 anti-lockdown protests on Twitter for Operation Gridlock and the armed protests resulting in the shutdown of the Michigan State Capitol. 16,383 tweets from 9,985 users mentioning #MichiganProtest, #MiLeg, #Endthelockdown, and #LetMiPeopleGo hashtags were collected over a 50-day period from April 01, 2020 to May 20, 2020. The analysis revealed the communities with the highest connective action properties and the top users within each community capable of orchestrating the protests. Establishing this theoretical framework will help researchers develop predictive models to understand when a connective action event is emerging and guide the measures needed to support or counter the action.

2 - A Novel Systematic Approach to Inspect Focal Patterns in Dynamic Social Networks
Mustafa Alassad, Nitin Agarwal

Malicious influential sets of users (focal sets) responsible for coordinating conspiracy theories, misinformation, and fake news campaigns have damaged the social networks' reputations over the past few years. Lots of methods applied to investigate and suspend the focal sets in static social networks. However, less inspiring research were employed to study and visualize the communities' behaviors in dynamic social networks due to shortage in good datasets and complexity in analysis after adding the time dimension. In this research, we propose a systematic approach to examine the evolution of focal sets in social networks over time. Our approach incorporates the focal structure analysis model to identify the influential sets of users coordinating to influence the maximum number of users in social network and the adaptation algorithm to observe their evolution over time. We evaluated our model in a real-world dynamic Twitter network utilized to coordinate mass protests called "The 26th October campaign" in Saudi Arabia, 2013. The resultant analysis was able to observe, predict, measure, and track the focal sets' influence over time and demonstrates the network dynamics. Likewise, this approach investigates and illustrates when these focal sets escalate their activities, where to concentrate their actions, and which focal sets are more proactive than others in the network.

■ TF-43

Tuesday, 18:30-20:00 - Virtual Room 43

Tournament design

Stream: OR in Sports
Invited session
Chair: *Arseniy Stolyarov*

1 - "Choose Your Opponent": A New Knockout Design for Hybrid Tournaments
Julien Guyon

We present a new, simple knockout format for sports tournaments, that we call "Choose Your Opponent", where the teams that have performed best during a preliminary group stage can choose their opponents during the subsequent knockout stage. The main benefit of this format is that it makes the group stage more exciting, by giving teams a strong incentive to perform at their best level. It also makes the group stage more fair, by limiting the risk of collusion, effectively canceling the risk of tanking, and making sure that the best group winners are fairly rewarded. The choosing procedure would add an exciting strategy component to the competition. Advancing teams would choose their opponent during new, much anticipated TV shows which would attract a lot of media attention. We illustrate how this new format would work for the round of 16 of the UEFA Champions League, the most popular soccer club competition in the world.

2 - Tournament Design for the ICC Cricket World Cup
Chris Potts, Neil Riley

There has been a variety of different formats used for the ICC Cricket World Cup since the competition started in 1975. This study analyses these different formats, including some new variations, with a view to selecting one or more having the most desirable features. Recent World Cup tournaments have involved two phases. The first phase is a round-robin tournament (sometimes preceded by an initial round-robin that will eliminate some of the weaker teams), where the teams may be divided into pools. The second phase is a playoff in the form of a knockout tournament. For the playoff phase, we introduce alternatives formats to the ones used in previous World Cup tournaments. A simulation model is presented that compares the different formats. The comparison is based on a 2019 setting with the probabilities of teams winning an individual match obtained from the pre-tournament betting odds for the 2019 World Cup matches. Each match in the simulation is classified in terms of its interest. For example, a match between two teams both having a chance of qualifying for the playoffs is of much greater interest to spectators than a match between two teams that cannot qualify for the playoffs. Results from the simulation show that the 2015 format, with an alternative design for the play-offs, produces the highest number of matches involving teams that can still benefit from winning the match to improve their position in terms of progressing to the next phase.

3 - Should we seed UEFA tournaments differently?
Arseniy Stolyarov

Seeding in tournaments is a mapping from past performance of teams to a schedule of a new tournament. This paper aims at measuring the effect of seeding on tournament results exploiting the discontinuous nature of seeding in European soccer (UEFA Champions League and UEFA Europa League). If seeding affects results in these tournaments then UEFA might consider changing tournament designs in order to achieve higher competitive balance and higher fairness in the tournaments. The first part of the project evaluates the impact of seeding on the expected results of teams (measured by the number of points in the group, place in the group and final result in the tournament). Current seeding procedure for drawing teams leads to situations when teams with similar rating and experience are deterministically seeded into different pots. The second part of the paper is going to provide counterfactual analysis of several alternative seeding procedures on the fairness and competitive analysis of UEFA Champions League and UEFA Europa League. First of all, the probabilistic model of game outcomes is estimated using discrete choice econometric models based on observable team and tournament characteristics, then, tournament simulations under different seeding techniques are run and competitive balance and fairness are measured.

■ TF-44

Tuesday, 18:30-20:00 - Virtual Room 44

OR v COVID in 5 minutes

Stream: Practice of OR (Making an Impact)
Invited session
Chair: *Ruth Kaufman*

1 - OR v COVID in 5 minutes
Ruth Kaufman

There is nobody at this conference who has not been affected by the COVID-19 pandemic. Many people in OR have been actively engaged in using their skills to address some of the huge range of challenges it has thrown up. This session bring together some of those speakers, with a series of 5-minute lightning talks showing how they have used OR to help overcome pandemic issues.

With a couple of breaks for discussion, this is a high-intensity, high-energy session which will showcase contributed abstracts across a wide range of OR methodologies and application areas.

'Making an Impact' lightning talks have been highly successful at previous EURO conferences and we are sure that this will be no exception.

The full list of papers and speakers will be finalised shortly before the conference starts, and will be available via the 'Making an Impact' webpages here: https://euro2021athens.com/specific-sessions/

■ TF-45

Tuesday, 18:30-20:00 - Virtual Room 45

OR in Agricultrure

Stream: Specific Applications of OR in Agriculture, Forestry and Fisheries
Invited session
Chair: *Lluís Miquel Plà-Aragonès*

1 - Optimal Planning Tool for Agricultural Waste Management in Vietnam
Trung Tran, Hoa Sen Le, Phùng Chính, Hoai Chung Pham, Phuong Le Nguyen, Phuong Huynh

Agricultural waste management in Vietnam has become a challenging issue for rural planners due to the lack of an efficient planning tool and the impact of climate change. As a result, it has increasingly caused air and water pollution in many rural areas of the country. In this talk, we present a mathematical programming model for rural planners to optimally locate facilities that produce bio-organic fertilizer from waste, and to determine the optimal set of routes for a fleet of vehicles to collect and transport the waste from farms to facilities. In the location-routing problem, we investigate unreliability in facility location and vehicle routing planning due to the risk of disruptions to location sites and roads (i.e. unexpected failure of location sites and roads due to flood impact). The proposed model aims to minimize total expected cost of locating facilities and routing vehicles under the risk of disruptions (due to flood impact) such that the amount of waste at farms is totally collected to maximize economic and environmental benefits. This model is tested and validated for the agricultural waste management in Quang Tri province, Vietnam.

2 - Data-driven Planning in the face of Supply Disruption in Global Agricultural Supply Chains
Marie Pelagie Elimbi Moudio, Cristobal Pais

The intricacies of global food networks have been exacerbated by increased globalization, advances in farming/logistics technology, and a rising agricultural exchange between countries. Certain economies, especially regions with low agricultural yield, rely on food imports and are susceptible to food insecurity due to potential negative disruptions to the global food network. These rising complexities in global food networks result in increased dependencies between countries, rendering the overall network extremely vulnerable. Local disruptions to production levels could entirely cripple the food network and lead to long-term reduced food access worldwide. Understanding the impact of different disruptions and potential mitigation strategies at the country level on agricultural supply chains becomes important in the analysis of the global allocation of agricultural products. We model a stochastic resource allocation problem with non-linear connectivity costs to capture trade dynamics between countries. We compare model recommendations to historical trade flow data including coffee import/export between countries, unveiling the value of centralized planning under potential disruption scenarios against the current practices.

3 - Application of GEE cloud, sentinel-2 and landsat8 imagery for crop area mapping, crop quality and rainfall extraction at ward level in Kwazulu-Natal.
Noe Careme Fouotsa Manfouo, Dieter Von Fintel

Modern Earth Observation (EO) technologies, especially those EO datasets comprising a multi-year data archive, such as landsat8 and sentinel2 lend themselves to land-cover change studies. A survey of studies performed in South Africa, and especially in Kwazulu-Natal, in terms of agricultural land cover change do not display a disaggregated information, useful to study food security at microeconomic level. The availability of this data will enable the investigation of the incidence of the 2016 drought and 2020 lockdown on crop land surface area and food security. This study, is an attempt to address such data issue, using reference data points obtained from Geoterraimage and additional data points collected on 20 meters high resolution, sentinel2 remote sensing imagery. The data points obtained are used with a random forest classifier, in the Google Earth Engine cloud platform to classify 828 wards, and extract the surface area of crops, the NDVI as well as the rainfall data. The results exhibit the ability of random forest to classify crop and non-crop, with an average accuracy of 95.25%, and a kappa index of 89.42%. The visual assessment confirms the high classification accuracy. The data obtained show that drought had a higher impact on crop area in homelands, with a decrease of −6.82%, as compared to −6.26% in non-homelands, but farmers in homelands showed better resilience. In contrast, the data indicated more resilience of non-homelands farmers to the lockdown effect

■ TF-46

Tuesday, 18:30-20:00 - Virtual Room 46

Dynamic Pricing

Stream: Revenue Management and Pricing
Invited session
Chair: *Jochen Gönsch*

1 - Scalable Relaxation Techniques to Solve Stochastic Dynamic Multi-Product Pricing Problems with Substitution Effects
Rainer Schlosser

In many businesses, firms are selling different types of products, which share mutual substitution effects in demand. To compute effective pricing strategies is challenging as the sales probabilities of each of a firm's products can also be affected by the prices of potential substitutes. In this paper, we analyze stochastic dynamic multi-product pricing models for the sale of perishable goods. To circumvent the limitations of time-consuming optimal solutions for highly complex models, we propose different relaxation techniques, which allow to reduce the size of critical model components, such as the state space, the action space, or the set of potential sales events. Our heuristics are able to decrease the size of those components by forming corresponding clusters and using subsets of representative elements. Using numerical examples, we verify that our heuristics make it possible to dramatically reduce the computation time while still obtaining close to optimal expected profits. Further, we show that our heuristics are (i) flexible, (ii) scalable, and (iii) can be arbitrarily combined in a mutually supportive way.

2 - Dynamic Pricing under Competition using Reinforcement Learning
Alexander Kastius, Rainer Schlosser

Dynamic pricing is considered a possibility to gain an advantage over competitors in modern online markets. The past advancements in Reinforcement Learning (RL) provided more capable algorithms that can be used to solve pricing problems. In this paper, we study the performance of Deep Q-Networks (DQN) and Soft Actor Critic (SAC) in different market models. We consider tractable duopoly settings, where optimal solutions derived by dynamic programming techniques can be used for verification, as well as oligopoly settings, which are usually intractable due to the curse of dimensionality. We find that both algorithms provide reasonable results, while SAC performs better than DQN. Moreover, we show that under certain conditions, RL algorithms can be forced into collusion by their competitors without direct communication.

3 - Dynamic Pricing in Shared Mobility Systems
Christian Müller, Jochen Gönsch, Matthias Soppert, Claudius Steinhardt

A free-floating carsharing system offers customers the flexibility to pick up and drop off an available vehicle at any location within the provider's business area. This flexibility has the drawback of often occurring distribution imbalances of vehicles within the network. There are two different strategies to counter this imbalance. The first one is realized by the provider through manual relocation and the second is carried out by the customers by providing monetary incentives for certain vehicles dependent on the number of available vehicles in vicinity. We developed a dynamic pricing approach for the second strategy based on dynamic programming to maximize profit. Due to the curse of dimensionality, we use a dynamic programming approach, which approximates the expected future revenue by considering the historical profit of vehicles in the near vicinity.

4 - Nonlinear Dynamic Pricing in the Presence of Multiunit Demand
Rouven Schur

Enabled by technological developments, dynamic pricing is gaining more importance in other fields than the airline industry. Thereby, it encounters new scenarios where neglecting multiunit demand leads to suboptimal prices and lost revenues. Whenever there is a finite stock and selling horizon as well as multiunit, stochastic, and price sensitive demand, a combination of dynamic and nonlinear pricing might be helpful to maximize expected revenue or profit. We consider a firm that is monopolistic and can price-discriminate between different order sizes by quoting batch prices. To reflect customers' decision regarding batch size, we adapt an adequate customer choice model based on random willingness-to-pay. Due to complexity of the optimization problem, we introduce two heuristics to solve the optimization problem approximately. We test both heuristics in a simulation study against an upper bound and analyze some patterns in the corresponding policies.

■ TF-47

Tuesday, 18:30-20:00 - Virtual Room 47

MINLP for Energy Networks

Stream: Mixed-Integer Nonlinear Optimization
Invited session
Chair: *Marius Roland*

1 - A bilevel framework for decision-making under uncertainty with contextual information
Miguel Angel Muñoz, Salvador Pineda Morente, Juan Miguel Morales

Since the deregularization of the electricity sector, determining the optimal market participation of a strategic producer under uncertainty has become a relevant task. Most existing models address this problem by forecasting, as accurately as possible, the residual demand curve. Then, such a forecast is used to compute the decision that maximizes the producer's profit. In this talk, we present an alternative data-driven procedure that considers the problem structure and leverage available auxiliary data to increase profits. From a mathematical point of view, our framework translates into a bilevel optimization model that is subsequently reshaped into a MINLP model with a convex objective function through a big-M-based reformulation. This model guarantees global optimality provided that the big-M values are properly selected. In this vein, we leverage a fast regulation-based reformulation of the original bilevel model to produce a local optimum solution with a twofold target, namely, warm-starting the MINLP model and providing an accurate estimate of the right big-M value. Both reformulations can be efficiently solved using well-known commercial optimization solvers. We demonstrate the superior performance of the proposed approach on a realistic case study that uses data from the Iberian electricity market.

2 - ACOPF in one retailer and several prosumers scenario
Martina Cerulli, Claudia D'Ambrosio, Leo Liberti, Martin Schmidt

The possibility for generation in private households has extended the activities of electricity customers from simply purchasing electricity, to taking a more active role within the production and storage of electricity, transforming themselves from purely power consumers to so-called "prosumers". In this scenario, we study an alternating current (AC) electricity grid, in a fixed discretized time horizon. Specifically, we derive a bilevel formulation to model the interaction between a retailer and prosumers, where the retailer is not part of the electricity grid but considered as an entity external to the set of prosumers who interact with each other through the network (each prosumer is a bus). The prosumers can produce power thanks to rooftop PV panels and store it in a battery. Each of them can potentially decide to sell some of the produced/stored (in a battery) power, receiving money from the government, which pays a fixed feed-in tariff for each unit of power sold (we will assume that the feed-in tariff is equal to the price of the power sold by the retailer). At the upper level, the retailer, who sets the price of electricity for a set of prosumers, aims to maximize his/her profit. At the lower level, prosumers (considered as acting together) aim to maximize the revenues from selling power/minimize what is paid to the producer when their production does not satisfy their power need.

3 - Convex hull pricing in markets with non-convex offers and AC OPF

Nicolas Stevens

Non-convexity is an unavoidable difficulty in electricity markets, that arises from (i) the inherent non-convexity of the physical laws governing the power grids as well as (ii) from the market orders that include binary decisions — the commitment decisions in the US-style markets or the so-called block bids in the EU-style markets. Besides the computational challenges that emerge from these non-convexities, their economical implication is that an equilibrium price supporting the market dispatch is not guaranteed to exist anymore. Fifteen years ago, a pricing model called Convex Hull Pricing has been proposed as a promising solution, exhibiting several desirable properties. This triggered a vivid debate in the academic literature as well as in the industry, among American ISO first and more recently also emerged in the European NEMOs discussions. This presentation investigates the convex hull pricing approach, provides an algorithmic solution to compute it and discusses its application in EU and US markets.

4 - Mixed-Integer Nonlinear Optimization for District Heating Network Expansion

Marius Roland, Martin Schmidt

We present an MINLP for computing optimal expansions of tree-shaped district heating networks given a number of potential new consumers. We state a stationary and nonlinear model of all hydraulic and thermal effects in the network as well as nonlinear models for consumers and the network's depot. For the former, we consider the Euler momentum and the thermal energy equation. For the thermal aspects, we develop a novel approximation. The expansion decisions are modeled by binary variables for which we derive additional valid inequalities. Finally, we present a case study in which we identify three major aspects that strongly influence investment decisions: the estimated average power demand of potentially new consumers, the distance between the existing network and the new consumers, and thermal losses in the network.

■ TF-48

Tuesday, 18:30-20:00 - Virtual Room 48

Lot-sizing

Stream: Lot Sizing, Lot Scheduling and Production Planning

Invited session

Chair: *Nabil Absi*

1 - Addressing the multistage integrated procurement and lot-sizing problem with demand fulfillment, backlogging and service levels

Caio Tomazella, Maristela Santos, Douglas Alem, Raf Jans

In this article we address the Multistage Integrated Procurement and Lot-Sizing Problem with multiple customers and backlogging. We were motivated by the case of a manufacturing company from Brazil that assembles refrigeration equipment, using raw materials purchased from overseas suppliers and in-house fabricated products. The objective of our study was to find solutions that are both cost efficient and that optimize service levels. Knowing that, in traditional cost minimization models, the backlog penalties are mostly intangible costs which are hard to estimate, we present models that optimize service levels while keeping the operational costs within a budget. Furthermore, we incorporate demand fulfillment decisions considering service levels for each customer separately. The results of our experimentation show that the proposed models are viable alternatives that surpass the need of using backlog costs, since they improve service levels when compared to the cost minimization models and can also be used to enforce service equity between customers. We analyze the trade-off between service levels, showing that it is possible to enforce equity by maximizing the lowest service level among the different customers without deteriorating global service levels. We also show how the models behave when the budget is tightened and propose adaptations of the models to maximize service levels considering customer and product importance, and to consider demand shortage as lost sales.

2 - Reformulations for the economic lot sizing problem with remanufacturing under demand and return uncertainty

Fernando Islas, Pedro Piñeyro, Carlos Testuri

In the economic lot-sizing problem with remanufacturing, the demand for a final product can be also satisfied by remanufacturing used products returned to the origin. Considering that demand and returns quantities are generally uncertain, we developed two stochastic variants of the problem according to whether manufacturing and remanufacturing are in separated or dedicated production lines. Stochastic mixed-integer linear programming reformulations are provided for both variants, assuming a finite discrete time planning horizon and finite probability space represented by scenario trees. The reformulations are mainly based on two different approaches: the facility location problem and the strengthening of the formulation by incorporating path valid inequalities. In addition, the path inequalities are combined to generate tree inequalities to further strengthen the formulations. A relax-and-fix heuristic is also proposed fot the case of large instances. We performed several computational experiments for the case of separate production lines, since it is the most complex variant of the two considered. Some key findings from the experiments are that the tree inequalities can improve the linear programming relaxation of the reformulations, and that the performance of the reformulations decrease as the number of periods increases. In addition, we note that the relax-and-fixed heuristic suggested shows promising results for large instances of the problem.

3 - Production Planning Applied to a Lattice Slabs Factory

Caroline de Arruda Signorini, Silvio de Araujo, Sônia Cristina Poltroniere, Gislaine Mara Melega

This study looks at the production planning of lattice slabs integrated to the optimization problem of the use of molds, motivated by a factory in Brazil. Lattice slabs are precast concrete structures composed of precast joists with steel latticed bars on a base of concrete. In the joists' production process, it is used a limited number of molds, which are divided into sections of equal lengths. The production planning of lattice slabs is weekly, and the production process starts with the preparation of the molds. Next, each mold is filled with concrete. The steel bars previously cut into the length of the items are used as reinforcement, being inserted into the still liquid concrete base. Subsequently, the items are removed from the molds, resetting the production cycle. Based on this production process, and considering the main concern of the studied factory related to the waste of steel bars during the cutting process and the minimization of the inventory level, we propose a mathematical model, which is an integrated lot-sizing and cutting stock problem, to minimize the inventory and production costs, subject to capacity and inventory constraints. We based the data set on real information obtained from a lattice slab local factory and also from specialized websites. The proposed model is solved by the Column generation procedure to generate the cutting patterns used in the production and a rounding procedure is applied to find an integer solution.

■ TF-49

Tuesday, 18:30-20:00 - Virtual Room 49

Queues, random walks and related models: Methods & Applications

Stream: Performance Evaluation of Queues
Invited session
Chair: *Ioannis Dimitriou*

1 - Heavy-traffic limit for a discrete-time two-class single server queueing model
Arnaud Devos, Joris Walraevens, Dieter Fiems, Herwig Bruneel

We consider a queueing system with one server and two queues. We assume the following way of sharing the server: at each service opportunity, the server chooses a queue with equal probability. We can now differentiate between two variants of this queueing system, depending on what happens when the server selects an empty queue. In the first variant, a customer of the other queue is served in order to keep the complete system work-conserving. In the second variant, no-one gets service for a given time since the chosen queue is empty. Although the latter is not the most efficient approach, this might be necessary in practical applications because of energy limitations or lack of knowledge of the queueing state. When we increase the mean arrival rates, it is expected that the event that an empty queue is chosen to be served occurs less often. Therefore, we derive the heavy-traffic limit of the joint queue-content distribution for both queueing models in order to investigate whether or not both alternatives give rise to the same limiting behavior.

2 - Integrated condition-based maintenance and lot-size planning
Alp Darendeliler, Dieter Claeys, El-Houssaine Aghezzaf

The lot-size problem has been studied frequently in literature. An efficient lot-size planning achieves a proper balance between setup costs, inventory holding costs, and lost sales costs. Nevertheless, a lot-size planning may turn out to be worthless when the machine that produces these products breaks down. A solution may be to add sensors to the machine, monitor the condition (degradation) of the machine, and take that condition into account in the planning problem. Although lot-size planning and condition-based maintenance have been studied by scientists, integrated lot-size and condition-based maintenance (CBM) planning is still a largely unexplored research topic. The few papers that consider this integration only consider lot-sizing in case of one product. Currently, however, machines have to produce various products due to the trend of shifting from mass production to mass customization. Therefore, we study the integrated lot-size and CBM planning problem in a multi-product setting. We develop a Markov Decision Process model where the state captures machine condition and inventory levels of the products. The objective is to obtain the optimal policy, that is the policy that minimizes the long-run discounted total cost. As the state space is exponential in the number of products, traditional dynamic programming methods are inadequate in computing the optimal policy. We, therefore, adopt reinforcement learning methods where experience is obtained through simulation.

3 - Approximation of exit probabilities of Stable Simple Random Walks in 3 dimensions
Cansu Aktepe İlter, Devin Sezer

We study a nearest neighbor stable three dimensional random walk X on the integer lattice, constrained to remain on the positive orthant. Let T_n be the first time the sum of the components of the random walk equals n. We develop approximation formulas for the probability P(T_n < T_0) using the affine transformation approach of (Sezer, Exit Probabilities and Balayage of Constrained Random Walks, 2015). Our results extend results obtained in (Unlu, Sezer, 2018) for two dimensional simple constrained random walks to three dimensions.

4 - Estimating customer impatience in a queue with balking
Liron Ravner, Yoshiaki Inoue, Michel Mandjes

We study a service system in which arriving customers are provided with information about the delay they will experience. Based on this information they decide to wait for service or to leave the system. The main objective is to estimate the customers' patience-level distribution and the corresponding potential arrival rate, using knowledge of the actual workload process only. We cast the system as a queueing model, so as to evaluate the corresponding likelihood function. Estimating the unknown parameters relying on a maximum likelihood procedure, we prove strong consistency and derive the asymptotic distribution of the estimation error. Several applications and extensions of the method are discussed. In particular, we indicate how our method generalizes to a multi-server setting. The performance of our approach is assessed through a series of numerical experiments. By fitting parameters of hyperexponential and generalized-hyperexponential distributions our method provides a robust estimation framework for any continuous patience-level distribution.

■ TF-50

Tuesday, 18:30-20:00 - Virtual Room 50

Energy Services in Buildings and Communities

Stream: OR for intelligent Energy Services
Invited session
Chair: *Zoi Mylona*
Chair: *Eleni Kanellou*

1 - Data-driven risk-based constraints for the optimal scheduling of an energy community
Mihály Dolányi, Kenneth Bruninx, Erik Delarue

In this research, we model the scheduling of an energy community composed of multiple distributed assets. The community is active in both day-ahead energy and real-time imbalance markets. We propose two risk-based constraints, using (i) the conditional-value-at-risk (CVaR) and (ii) the worst-case CVaR (WCVaR) functions to model the probabilistic enforcement of flexibility constraints. All reformulations result in linear expressions, thus allow for tackling large-scale stochastic models. The highly uncertain violation cost of the managed DERs makes the CVaR based constraint (CVaR-BC) particularly suitable, which in addition to the probabilistic characteristic, penalizes the severity of the violations. Secondly, we address the distributional ambiguity faced by the community manager when new sites are added to the portfolio with limited information on their historical load profiles and on the corresponding forecast error. This is done by utilizing the worst-case CVaR (WCVaR-BC) function that differentiates the CVaR value among different scenario groups and enforcing its fulfillment in the worst set. The proposed risky-constraints are then trained and evaluated on real data collected globally from several anonymous sites. Our findings indicate that using the WCVaR-BC leads to systematically higher out-of-sample robustness and lowers the exposure to extreme outcomes.

2 - A general optimization model for energy renovation of residential urban areas
Unai Aldasoro

The current climate crisis makes it pressing to take measures in order to improve the energy performance of the building stock. As buildings are responsible for 40% of the overall primary energy consumption of the European Union, the Directive 2010/31/EU aims that, in the next decade, all new buildings, and gradually the existing stock, should be nearly Zero Energy Buildings (the nearly zero amount of energy required should be covered to a very significant extent by energy from renewable sources). In this context, Operations Research should play a leading role in the decision making process. In this paper, a general model for the optimization of Energy Supply Systems and Energy Saving Measures is proposed. The model is based on a general superstructure that allows including all the existing and future technologies, optimizing the design selection of the renovation of buildings to meet different non-renewable primary energy consumption limits. Also, the operation time horizon has been discretized in a set of independent reference days, where the unit commitment of technologies is considered. The resulting model is a deterministic MILP. The method is applied to a neighborhood located in Bilbao (northern Spain), both in disaggregated (building optimization) and aggregated (district optimization) perspectives. An extension of the model to a two-stage stochastic optimization problem is also reported.

3 - Mitigating Energy Poverty through Joint Energy Initiatives

George Konstantopoulos, Eleni Kanellou, Christos Stefanatos, Vangelis Marinakis, Haris Doukas

Collective energy initiatives such as energy communities enable cities and regions to actively support the local community by implementing actions that empower citizens suffering from energy poverty while mainstreaming the use of clean energy. Energy communities are associated with creating a positive social impact enabling the uptake of innovative actions by the locals. By leveraging ICT enabled tools the members of the community can control their energy expenses and identify citizens suffering from energy poverty in a local level. Energy communities bring citizens in the heart of the solution engaging the locals, promoting the involvement of young people through the establishment of "next generation energy communities" and enabling anyone interested to get trained and become an Energy Supporter or Mentor providing guidance, or even establishing a Local Energy Poverty alleviation office serving as a one stop shop of support. Some of these actions are included in the H2020 POWERPOOR project aiming at designing, developing, and implementing energy poverty support schemes in eight different countries across Europe, Bulgaria, Croatia, Estonia, Greece, Hungary, Latvia, Portugal, and Spain. These countries appear to be scoring high in the energy poverty indices according to the Energy Poverty Observatory. Results from the implementation of the support schemes are presented along with the potential to incorporate energy poverty alleviation strategies in local energy planning.

4 - Data analytics for Improving the Financeability of Energy Efficiency Investments

Vangelis Marinakis, Themistoklis Koutsellis, Nikos Dimitropoulos, Aija Zucika, Haris Doukas

Energy efficiency (EE) projects are often fragmented, of high transaction costs, and fall below the minimum value that many private financial institutions are willing to consider. The finance community is lacking a tested, evidence-based platform, providing decision makers with support regarding the impacts of various investment criteria, risk-aware assessment, and performance applied on a pool of EE investments. The capability offered by emerging near big data analytics to integrate cross-domain financial and energy consumption is key to building the necessary market confidence in EE projects and making them an attractive investment asset class. The availability of comparable, anonymized historical data pooled from major market segments, structured along major project characteristics, can encourage greater EE investment flow. The aim is to present data-driven applications based on machine learning methods that can attract and mobilize private funding on such projects, providing investors/financiers (e.g., commercial/green investment banks, institutional/insurance funds, etc.) and project developers (public/local authorities, energy providers, ESCOs, construction companies, etc.) with data and tools to identify sustainable investment pathways and decrease the EE investment risk. Extensive data processing is applied to elaborate and categorize financing instruments and risk mitigation strategies, and to identify best practices on private financing as a basis for benchmarking.

■ TF-52

Tuesday, 18:30-20:00 - Virtual Room 52

Energy Policy, Economics and Markets

Stream: OR in Climate Policy and Planning
Invited session
Chair: *Dimitrios Angelopoulos*
Chair: *Haris Doukas*

1 - On the long-run development of the Greek power system towards deep decarbonization

Evangelos Chatzistylianos, Georgios Psarros, Stavros Papathanassiou

The fundamental objective of this paper is to investigate the long-run development of the Greek power system under high renewable energy source (RES) penetration levels and deep decarbonization. To this end, a capacity expansion model (CEP), built upon the Linear Programming mathematical optimization method is developed to determine the optimal generation mix of the system for a future target year. Model decision variables include system electricity storage requirements (pumped-hydro storage, battery energy storage and power-to-gas), RES installed capacities (wind on/offshore, photovoltaics, biomass, solar thermal stations) and natural gas-fired power plants with or without carbon capture storage capabilities. The power system is divided into two operating zones, which are weakly interconnected via a bipolar HVDC link; the mainland grid and the zone of Crete. For the sake of completeness, the CEP is suitably amended to incorporate transmission expansion capabilities, which are eventually utilized to determine the potential enhancement of the transfer capacity between system zones. CEP targets include a minimum RES penetration rate of 90% in tandem with a maximum annual RES curtailment rate of 5%.

2 - An Integrated Optimization of Production Planning and Day Ahead Electricity Market Bidding for Combined Cycle Natural Gas Power Plants

Hafsa Nur Öztürk, Kadir Ertogral

In this study, an integrated model is presented for a producer with a combined natural gas cycle power plant that maximizes its expected profit and proposes an hourly production plan and the Day Ahead Market (DAM) offers under market clearing price uncertainty. Market operator decides both market clearing price and amount for each hour for the next day. Thus, for each market participant, if a match is achieved, their obligations for the next day are reported. In DAMs there are two major order types applied which are single hour orders and block orders. Hourly orders can be selected at different hours within their valid hours. Block orders consist of consecutive hours that cannot be divided. Generating less electricity than the specified amount in the market causes incurring penalties, and generating excess electricity causes compromise from profits. Therefore, there is a relationship between bidding and production planning. The general modeling approach consists of two parts, namely the production model and the bidding model. In the production model, possible hourly production levels are made discrete and model chooses one of these discrete production levels for every hour. In the bidding model, it creates bids for DAM by considering the hourly production quantities. Since the market clearance price is stochastic parameter, we propose a sim-heuristic type solution approach for the problem and show the effectiveness of our approach on a set of real-life based problems.

3 - An Integrated Optimization of Production Scheduling and Bidding Decisions in the Energy Market for a System of Cascading Hydroelectric Power Plants

Sevde Nur Ozbolat, Kadir Ertogral

With the increasing demand for electricity, the need for renewable energy has also increased. As one of the most important renewable energy sources, hydroelectric power plants (HPP) have an important aspect compared to other renewable energy sources that is energy production in HPP is controllable. Thus, a company who owns HPP can decide the best times to generate electricity considering the status of HPP system, e.g. water levels at different reservoirs, and the dynamics of the selling prices of electricity in the market. In this study, we model and solve an integrated problem of production scheduling and bidding decisions in a day-ahead market for a cascading HPP system with multiple power plants. For the next day, since the bids have to be entered a day early, production scheduling part decides the hourly water flow management and energy production while the bidding part decides the offer prices and amounts of energy commitments on an hourly basis. Offers are both single hour or block-hours types, and there are several market rules that model has to take into account. The key parameter of the entire model, which is a random variable, is the hourly energy prices in the market on the next day, and this parameter turns the problem into a stochastic optimization one. We suggest a sim-heuristic type solution approach for the solution of the problem and show the effectiveness of our solution approach on a set of problems that are both randomly generated and real life based.

■ TF-53

Tuesday, 18:30-20:00 - Virtual Room 53

Modelling tools II

Stream: Software for Optimization
Invited session
Chair: *Susanne Heipcke*
Chair: *Jens Schulz*

1 - Introducing JSON Based Language To Deliver Data For Deploying Optimization Models through REST API Service On The Cloud
Bjarni Kristjansson

When preparing optimization models for deployment, it is often not the formulation of the model or the solving that is the most difficult part, but rather how to organize and deliver the data efficiently to the model. Using modeling languages, this problem can be alleviated by importing data directly from SQL databases and spreadsheets, but this is still not easy enough. In this presentation, we will demonstrate how using the JSON data format can be particularly well suited for organizing optimization data. Furthermore, using SQL and NoSQL databases such as MySQL, MongoDB and BigQuery, which are very efficient at storing dynamic data, give the model developer new opportunities for deploying optimization on the cloud.

2 - Leveraging Compute Infrastructure for High-Performance & Enterprise-Grade Optimization Applications
Jens Schulz

With mathematical optimization techniques, we are able to solve an incredibly broad range of practical problems - from scheduling, vehicle routing, network optimization, packing and cutting, just to name a few. Most real-world problems can easily grow in size to an extent such that decomposition techniques need to be applied. Furthermore, web UI servers that manage user workloads should not get bogged down with computing tasks. Here, a separation and dedicated specification of client servers and compute servers is desired.

In this presentation we will demonstrate how the new FICO' Xpress Insight Compute Interface can be used to improve the performance of decomposed models and supports separation of concerns. We will take a look at some examples from practice where we need to decrease run time and accomplish this by parallelizing the execution of sub models. Further, for practical applications we demonstrate how to use dedicated machines for compute-intensive jobs while sending only data from lightweight client applications such as mobile or web applications to the compute servers. Thus, enabling separation of concerns in enterprise-grade environments.

3 - The new R Interface of FICO Xpress
Daniel Junglas, Gregor Hendel

In its latest version, the FICO Xpress Optimizer introduces an interface to R, a language and environment for statistical computing and graphics. This interface allows taking full advantage of the Optimizer from inside R. This even includes callbacks and multi-threading. We will present the new interface and illustrate with some examples how to use the Optimizer from R.

4 - Progress on Functions in AMPL
David M. Gay

A "beta" extension to the AMPL modeling language allows functions to be declared in AMPL. AMPL has long allowed using functions from shared libraries, written in other languages. Functions directly expressed in AMPL should make some forms of modeling easier. In particular, providing callbacks to solvers should be easier with functions expressed directly in AMPL. Initially AMPL functions are just available in AMPL itself, where they enable alternate ways to construct scripts. An extension to functions from shared libraries allows such functions to return tuples and sets to an AMPL session. Later, AMPL functions and their closures will be conveyed to solvers as part of an enhanced solver-interface facility, which will also entail some automatic differentiation machinery different from that in the current interface library.

■ TF-55

Tuesday, 18:30-20:00 - Virtual Room 55

Better Decisions with Data II

Stream: EURO Working Group Data Science meets Optimisation
Invited session
Chair: *Yingqian Zhang*

1 - Data-driven expert opinion calibration and aggregating: simulation study of the effects on decision making
Risto Heikkinen

Data-driven decision making refers to making decisions based on data available. The data may be augmented by information from human experts, other than actual decision makers. By incorporating this information, more accurate decision problems can be modelled. However, there are challenges since subjective human judgements include biases and overconfidence and some experts may be more experienced than others. Therefore, one should not regard each expert's opinion equally relevant. Quantiles, i.e. cut points dividing a probability distribution into intervals with equal probabilities, of an unknown continuous variable can be asked from experts to quantify their views as a probability scale. These quantiles describe the location of a single expert's probability distribution of an unknown quantity and uncertainty experienced. Earlier judgements from the same experts give information about their biases. If only point estimates (mean/median) are asked, the process reduces to a forecast pooling problem. We study methods for calibrating and aggregating multiple expert views within a Bayesian framework and conduct simulation experiments to study the usefulness for decision making. We also study how unrealistic assumptions and using only point forecasts instead of a set of quantiles affect decisions. We use stock portfolio allocation decisions as an example but also discuss more general applicability in data-driven optimization and decision making.

2 - Adaptive recommendation system for taxi drivers
Duy Hoang Tran, Pieter Leyman, Patrick De Causmaecker

Taxi recommendation systems aim to provide taxi drivers with guidance on how to find new passengers, and two recommendation methods are mainly adopted in the literature. Point recommendation presents taxi drivers with popular locations to wait for the next trips (waiting strategy), while route recommendation provides cruising routes to hunt for passengers (hunting strategy). However, one strategy may be more effective than the other in a specific area during a particular period of the day. How to take advantage of historical trajectory data to provide taxi drivers with optimal recommendation is still an active and challenging problem. In this work, we propose an adaptive recommendation method that provides taxi drivers with the appropriate recommendations according to time and location. Firstly, strategy patterns are investigated to find the most effective strategy in a specific area and a particular time window. Secondly, recommendations are adaptively made by three recommendation methods: point recommendation, route recommendation, and personalised recommendation. The proposed method is evaluated on real-world taxi trajectory data from New York City. The experimental results show that the adaptive recommendation method helps improve the average net profit of taxi drivers.

3 - A Learning Relocation Policy for Dynamic Ride-Sharing
Jarmo Haferkamp, Marlin Wolf Ulmer, Jan Fabian Ehmke

Dynamic ride-sharing services operate large fleets of vehicles to fulfill incoming trip requests on demand. Due to the short-term nature of requests, relocation of idle vehicles is crucial for their success. The objective for relocation policies is to offset unbalanced distributed trip origins and destinations to avoid demand surpluses, i.e. the rejection of requests. Along with potential demand surpluses, relocation decisions have to consider further decision criteria such as travel distances or other relocations. Our aim is to learn on a tactical level how to weight these decision criteria, while at the operational level deciding on the exploitation of myopic or anticipatory information to achieve a balanced and robust ride-sharing system. To this end, a two-step learning process is proposed. First, the weights are iteratively learned while updating expected demand surpluses, as anticipatory information. Secondly, it is learned how to vary the influence of expected and realized demand surpluses on the decision-making process as a function of system performance. Both steps are implemented by combining Bayesian optimization to identify promising parameter values with simulation to their evaluation. Regarding these learning process, we analyze resulting decision patterns as well as conditions under which their benefits alter. Moreover, the obtained policy will be benchmarked against several variants and a myopic policy from the literature.

■ TF-58

Tuesday, 18:30-20:00 - Virtual Room 58

Home Health Care

Stream: ORAHS: OR in Health and Healthcare
Invited session
Chair: *Melanie Reuter-Oppermann*

1 - An integrated Multi-Period Combinatorial Auction and Nurse Routing Problem for home health-care services
Valentina Bonomi, Daniele Manerba, Renata Mansini

We study an integrated Multi-Period Combinatorial Auction (MPCA) and Nurse Routing Problem (NRP) to better support hospital home health-care decisions in facing overcrowding due to the current COVID-19 pandemic. The MPCA allows to entrust part of the visits to external providers while the NRP generates routes for each nurse managed directly by the hospital. To participate in the auction, external providers indicate the subset of visits they intend to carry out for each patient and the price required for the service. The objective of the hospital is to decide on the outsourcing policy while minimizing at the same time the costs of the providers (auction costs) and the traveling costs related to the internally managed visits. The described routing and scheduling problem is further complicated by the presence of time windows, which impose that visits occur in accordance with patients availability, and consistency constraints, which commit the hospital to ensure a high QoS by limiting the number of nurses providing care to the same patient. We provide a Mixed-Integer Linear Programming formulation for the resulting overall problem and an effective heuristic procedure based on decomposition. The solutions obtained on realistic instances with a different number of providers and consistency levels allow us to investigate how different degrees of collaboration with external companies impact both internal logistics of the hospital and QoS.

2 - Routing and scheduling for a home care business
Isabel Mendez Fernandez, Silvia Lorenzo-Freire, Ángel Manuel González Rueda

In this work we present a routing and scheduling problem for a home care business. The goal of this problem is to schedule the routes that the caregivers must follow in order to carry out the users' services. To have feasible schedules we need to take into account caregivers' and users' hard time windows, as well as the caregivers' maximum working time. We also need to consider users' soft time windows, caregivers agreed working time and affinity levels between caregivers and users.

There are two objectives in this problem: the cost of the schedule (composed of the caregivers' overtime and their working time) and the users' welfare (composed of the affinity between users and caregivers and the penalization for performing the services outside their soft time windows). According to these objectives we have two different approaches: one that prioritizes the cost of the schedule, which is used for cases when the company starts working in a new area, and another one that prioritizes the users' welfare, which is used when the company is already attending the users.

To solve the problem, we propose a mixed integer programing problem, that can be used to solve instances of small size, and a heuristic algorithm, that can solve large size instances. This algorithm combines the Adaptive Large Neighbourhood Search method, which is used to modify the routes, with two scheduling strategies that consider the aforementioned approaches.

3 - A New Optimization Approach for Home Health Care Scheduling Problem
Mariem Belhor, Adnen El Amraoui, François Delmotte, Abderrazek Jemai

Facing the third wave of the coronavirus epidemic, it is necessary to free up the maximum number of beds in hospitals. Home Health Care (HHC) offers an alternative to the traditional hospitalization by reducing the occupancy rate in hospitals. In this context, the care should be provided by a multi-professional team, including doctor, nurse and oxygen therapy provider. However, one of the main challenges for healthcare decision-makers is to minimize costs by optimizing workforce scheduling. This research deals with the HHC optimization problem that involves the routing and scheduling of the medical staff. The considered problem is an extension of multiple Traveling Salesman Problem (mTSP) that consists of finding the shortest path for a set of employees who perform services at patients homes. Therefore, a Mixed Integer Programming (MIP) model, which aims to minimize the overall service times by balancing the workload between employees is proposed. A new genetic algorithm (GA-mTSP) based on learning curves approach (LC) is then developed to solve the proposed model. The main idea of integrating LC is to balance the workload between employees based on their experiences. The proposed approach is validated on mTSP benchmark data and compared to the obtained results of GA-mTSP without LC. Simulation results prove the impact of LC on workload balancing and its effectiveness to minimize service times.

4 - Mathematical Modelling for dynamic Home Health Care routing with Cumulative Objective Function
Juan S Nino-Rivera, Angélica Sarmiento Lepesqueur, William Guerrero

Logistics management in healthcare systems has been a major focus area for operations research in the recent years. However, traditional approaches consider optimization goals related to costs and financial effectiveness. In this paper, we address a specific scenario of the home healthcare vehicle routing problem, considering the dynamic nature of new requests made by patients. We propose a two-stage solution approach by building an initial set of routes. The second stage optimaly adapts the previous set of routes as information about new patients' requests is available. We propose a weighted cumulative objective function that sums for every patient the response time weighted by a priority assigned for their services during the request. Moreover, this customer-oriented objective function seeks to maximize customer satisfaction by reducing the waiting time. Our approach also considers constraints regarding time windows promised to patients, multiple vehicles departing from and arriving to multiple dispatch centers, as well as constraints related to the number of changes allowed for a route. Finally, we propose a multi-start VND algorithm to solve the problem achieving a gap under 1% and reducing solve time on average in 80% compared to commercial solvers. Results demonstrate that it is possible to effectively address these problems and maximize customer service.

■ TF-60

Tuesday, 18:30-20:00 - Virtual Room 60

Exact methods for cutting and packing problems

Stream: Cutting and Packing
Invited session
Chair: *Jean-François Côté*

1 - Combinatorial Benders Decomposition for the Two-Dimensional Bin Packing Problem
Jean-François Côté, Mohamed Haouari, Manuel Iori

The two-dimensional bin packing problem calls for packing a set of rectangular items into a minimal set of larger rectangular bins. Items must be packed with their edges parallel to the borders of the bins, cannot be rotated, and cannot overlap among them. The problem is of interest because it models many real-world applications, including production, warehouse management, and transportation. It is, unfortunately, very difficult, and instances with just 40 items are unsolved to proven optimality, despite many attempts, since the 1990s. In this paper, we solve the problem with a combinatorial Benders decomposition that is based on a simple model in which the two-dimensional items and bins are just represented by their areas, and infeasible packings are imposed by means of exponentially many no-good cuts. The basic decomposition scheme is quite naive, but we enrich it with a number of preprocessing techniques, valid inequalities, lower bounding methods, and enhanced algorithms to produce the strongest possible cuts. The resulting algorithm behaved very well on the benchmark sets of instances, improving on average on previous algorithms from the literature and solving for the first time a number of open instances.

2 - A Branch-and-Price Algorithm for the Multiple Knapsack Problem
Olivier Lalonde, Jean-François Côté, Bernard Gendron

The Multiple Knapsack Problem (MKP) is a combinatorial optimization problem with several applications. It consists of packing some subset of n items into m knapsacks such that the total profit of the chosen items is maximum. A novel Lagrangian relaxation based on a reformulation of the problem is presented, and it is proven that it dominates all commonly used relaxations for this problem. A branch-and-price algorithm (BP-MKP) is then derived from it, which takes advantage of the fact that the novel Lagrangian relaxation makes it possible to effectively control whether an item is included in some knapsack or not. An improved algorithm for solving the resulting packing subproblems is also introduced. Computational experiments then show that the new approach achieves state-of-the-art results.

3 - Novel Reformulations for the Single-Sink Fixed-Charge Transportation Problem
Robin Legault, Jean-François Côté, Bernard Gendron

The single-sink fixed-charge transportation problem is known to have many applications in the area of Manufacturing and Transportation as well to be an important subproblem of the fixed-charge transportation problem. However, even the best solutions of the literature do not succeed in fully exploiting the structure of this problem, to the point of being surpassed by modern general-purpose mixed-integer programming solvers for large instances.

In this paper, we introduce binary integer programming reformulations of the problem and study their theoretical properties, which lead to a range of new upper and lower bounds as well as specific dominance relations, linear relaxations and filtering procedures. The resulting algorithm includes a heuristic phase and an exact phase, the main step of which is to solve a very small number of knapsack subproblems.

Computational experiments are presented for existing and new types of data instances. These tests indicate that the presented algorithm systematically reduces the resolution time of the state-of-the-art exact methods by several orders of magnitude.

4 - On pattern reconfiguration in one-dimensional cutting stock patterns
Fatemeh Kafash Ranjbar, Claudio Arbib, Fabrizio Marinelli, Ulrich Pferschy

When industrial components are obtained by cutting sheets of raw material, production quality can be affected by unpredictable defects that can appear in the sheets. In this work, we consider a setting with a uniform supply of sheets, each of which might have a defect position with a certain probability. In case of such a defect, the pieces to be produced from this sheet cannot be exchanged anymore, but their position on the sheet can be reconfigured. In this way, one can either avoid any loss by assigning a trim loss piece to the damaged area, or one has to remove a piece from the production plan. We propose a simple mathematical model to deal with this production planning problem based on the design of one-dimensional cutting patterns that can be reconfigured to avoid, as far as possible, defective areas or minimize the incurred loss. Clearly, it would increase the chances of reconfiguration around a defect position if the cutting pattern of the bin has more slack. Therefore, we study the trade-off between increasing the number of bins in the solution (causing an increase in cost) and the resulting increase in the expected profit of the produced products under various damage probabilities. To reach a balanced distribution of items to bins the corresponding multiprocessor scheduling problem is solved by a standard ILP approach. We perform computational experiments to illustrate the gains and limitations of this defect avoiding strategy for various profit to cost ratios.

■ TF-61

Tuesday, 18:30-20:00 - Virtual Room 61

Information Problems in Queues with Strategic Customers

Stream: Queues with Strategic Customers
Invited session
Chair: *Philipp Afèche*

1 - The impact of information in a transportation station with strategic customers
Antonis Economou, Dimitrios Logothetis

Nowadays, a transportation station has the possibility to provide its potential passengers with information regarding the arrival times of the successively arriving facilities, the congestion in the station and the space availability of future facilities. Such information influences the behavior of the passengers who think strategically and consequently the welfare that is generated by the system.

In this talk, we will describe a general model of a transportation station where strategic customers arrive according to a Poisson process, the arriving instants of the transportation facilities form a renewal process and the capacities of successively arriving facilities are finite. Customers decide whether to stay or balk based on their expected waiting costs and the probability of being served, conditioning on the information provided.

The capacity of the next facility is communicated to the customers. Moreover, additional information such as the elapsed time from the previous visit of the facility and/or the number of waiting customers may also be provided. We will show how the customer equilibrium strategies can be derived and how the corresponding key performance measures can be computed, under various information structures.

Finally, we will present various numerical results and discuss the ideal level of information that should be provided according to the operational and economic parameters of a given system.

2 - The Structure of Optimal Delay Announcements for Throughput Maximization: A Bayesian Persuasion Perspective

Nahum Shimkin

We consider a service system to which customers arrive sequentially. Upon arrival, each customer receives from the system some information about his or her expected delay (or another measure of the quality of service), which is not directly observed by the customer, who then decides whether to join or avoid the offered service. The system is committed to truth telling, but may provide only partial information (such as a range of expected delays rather than the exact one). We ask what information should be provided to arriving customers to maximize the system throughput, namely the fraction of customers that choose to join. This problem is naturally formulated within the framework of Bayesian persuasion, where the customers' preferences of joining at given delays are captured through a population demand curve. We derive explicitly the form of the optimal solution, which depends on the convexity or concavity properties of the demand curve.

3 - Unreliable Information Transfer in the Markovian Single Server Queue

Gail Gilboa Freedman, Yoav Kerner

The goal of this work is to bring concepts of information unreliability from information theory, to world of strategic behavior of customers in queueing systems.

In many game settings, the information about the actions of the agents is unreliable (or noisy). We propose a model that formalizes this noise as a function that maps each optional action into a distribution over the set of signals. We identify this process with a row stochastic matrix where an entry denotes the conditional probability of the signal given the actual action.

In queueing perspective, the noise associated with customers' actions is reflected to a noise on the observed state of the queue. We consider the first-come first-served observable single server queue, with Poisson arrivals, exponential service, linear waiting costs, fixed rewards from obtaining service, and no reward from balking.

In this model, the equilibrium solution is a dominant pure threshold strategy, and the social welfare is associated with this threshold. In our proposed modification of this setting, the social welfare is also associated with the details of the stochastic matrix, as it has influence on the observed length of the queue and the choices of the arriving customers.

We will use a combination of analytical and numerical approaches to investigate the ratio of the social welfare in our setting and that of a standard setting (with reliable information about the choices of the customers).

4 - Learning and Earning for Congestion-prone Service Systems

Philipp Afèche, N. Bora Keskin

We consider a profit-maximizing service provider that serves price- and delay-sensitive customers. The provider operates an unobservable first-come-first-served M/M/1 queueing system over T decision epochs, where each epoch is sufficiently long for the system to reach steady state.

The provider faces Bayesian uncertainty regarding customers' price- and delay sensitivity, and can dynamically collect noisy demand observations. In each epoch, the provider chooses the price and the expected lead time to quote customers, and the system capacity.

We characterize the structure and the profit performance of the myopic Bayesian price/lead-time quotation policy and well-performing variants. Our results identify and explain the critical interplay between the capacity cost, profit performance, and learning.

■ TF-63

Tuesday, 18:30-20:00 - Virtual Room 63

YoungWomen4OR - Graphs, Networks and Transport

Stream: YoungWomen4OR

Invited session

Chair: *Annunziata Esposito Amideo*

1 - Applied network design problems to support Social Good

Jessica Rodríguez-Pereira, Burcu Balcik, Marie-Ève Rancourt, Gilbert Laporte, Selene Silvestri

Natural disasters cause significant losses by inflicting severe physical and economic damage to affected areas. The frequency and impact of natural disasters is increasing in number and intensity. For example, the Caribbean region is under permanent threat from devastating hurricanes. Large-scale earthquakes also affect several countries, such as Nepal in April 2015. To mitigate the consequences of such disasters, new methodologies are developed to address two cases of network design for planning logistics decisions in humanitarian operations. The first case deals with the design of a regional pre-positioning network to ensure a quick and effective response in the Caribbean area in collaboration with the Caribbean Disaster Emergency Management Agency. The objective is to develop a tool that provides an effective collaborative pre-positioning network and a systematic cost-sharing methodology to determine the contributions of countries in the establishment and administration of the network. The second case, in collaboration with the Austrian Red Cross and the Z-GIS department of the University of Salzburg, studies the restoration of the drinking water supply system in Nepal. The objective is to model and solve the design problem of a community water distribution network fed by gravity. The main objective is to identify the best location for community water taps and assign households under standardized conditions. Secondary, water supply network cost must be minimum.

2 - Urban Air Mobility: A model for tactical deconfliction

Mercedes Pelegrín, Claudia D'Ambrosio, Rémi Delmas, Youssef Hamadi

Urban Air Mobility (UAM) has the potential to revolutionize transportation. This emerging paradigm in mobility will exploit the third dimension to smooth ground traffic in densely populated areas. In this context, automatization of traffic management is key to ensure safety and optimize airspace capacity. This work addresses the problem of Pretactical and Tactical Deconfliction in UAM, considering up to three different scenarios standing for different sources of disruption. We leverage envisioned UAM corridors to provide a mathematical definition of vehicle separation. A mathematical programming model is proposed, which provides a common modeling framework for the three scenarios. Extensive computational experience on synthetic networks showcases the benefits of the proposed approach over local deconfliction, and demonstrates its potential as a real-time decision support tool.

3 - Coordinating drones with mothership vehicles: The mothership and drone routing problem with Graphs
Lavinia Amorosi, Justo Puerto, Carlos Valverde

This talk focuses on the optimization of routing problems with drones. It analyzes the coordination of one mothership with one drone to obtain optimal routes visiting some target objects modeled as general graphs. The goal is to minimize the overall weighted distance traveled by both vehicles while satisfying the requirements in terms of percentages of visits to targets. We discuss different approaches depending on the assumption made on the route followed by the mothership. In all cases, we develop exact formulations resorting to mixed integer second order cone programs that are compared on a testbed of instances to assess their performances. Besides the exact formulations we also provide a tailored matheuristic algorithm that allows one to obtain high quality solutions in reasonable time. Computational experiments show the usefulness of our methods in different scenarios.

4 - Shared mobility: integrating fleet and revenue management under uncertainty
Beatriz Brito Oliveira

Shared mobility systems, such as carsharing or car rental, face significant fleet management challenges. Also, their flexibility allows using pricing to influence demand. This flexibility is higher than in other traditional revenue management sectors, e.g. airlines, since it is easier to move and increase/decrease resources. Despite growing research interest, there is still the need to understand, model and manage demand better. There are also advantages in integrating this knowledge within fleet operations, especially under uncertainty. This communication presents an overview of the work developed in this context. We study the interactions between fleet and revenue management in carsharing and car rental and proposed an integrated model for the latter, considering uncertainty in demand and competitor prices. This is a practical application with many uncertain parameters with unknown probability distributions. We propose that metaheuristics, namely based on genetic algorithms, can generate relevant and complex scenarios in such cases. We developed an innovative approach based on a co-evolutionary metaheuristic, where solutions and scenarios are generated and evolve in parallel. The goal is to generate solutions that perform well when facing a diverse scenario population, considering their impact on solution quality. This method can be applied to other problems. Moving forward, we aim to focus on sustainability issues, namely by focusing on multimodality in urban mobility

Wednesday, 8:30-10:00

■ WA-01

Wednesday, 8:30-10:00 - Bulding A, Amphitheatre

New frontiers in risk management

Stream: Enterprise risk management
Invited session
Chair: *Anoop Rai*

1 - Tree-Based Ensemble Strategies for Predicting Loss Given Default of Bank Loans
Aida Salko

We investigate the performances of eight different tree-based ensemble techniques for predicting Loss Given Default of bank loans for Small and Medium Enterprises (SMEs) and large corporates. Using a unique dataset of defaulted loans in European banks, we show that these ensemble strategies lead to remarkable improvements in LGD prediction accuracy compared with regression trees. Random forest performance prevails among other tree-based ensembles. Additionally, we use SHapley Additive exPlanations (SHAP) method to analyze the contribution of individual risk drivers in prediction and provide some insights about their influence on model prediction through partial dependence plots. We find that the algorithm considers different important features for SMEs and large corporates. It is shown that the default amount, the reported entity sales followed by the industry sector, and macroeconomic environment turn out to be important drivers for an accurate prediction of LGD in the case of SMEs. On the other hand, for large corporates, including information regarding the entity reported financial information when training random forest algorithm, strongly enhance the forecasting performance of the model.

Keywords: Loss Given Default, Global Credit Data (GCD), Forecasting, Ensembles.

2 - Monetary Policy and Macroeconomic News in Central Bank Announcements of Mexico
Anoop Rai

Recent research has decomposed the information content of central bank announcements into two types of news, monetary policy news and macroeconomic news (Jarociński & Karadi, 2018). Monetary policy news reveals the choice of action by the central bank to manage the new macroeconomic information. Hence, analysts and central bank observers have to predict not only the future state of the economy but also the central bank's choice of monetary policy action. This study examines the central bank announcements of Banco de México for the period 2000 to 2020. There are three phases during this period. Between 2000-2003, the central bank targeted the level of banks' current account balances at the central bank (corto), resulting in near daily changes to the monetary policy rate changes. In 2004, the central bank also targeted the interest rates, specifically by announcing minimum overnight rates, resulting in fewer changes during the year. Finally, in 2008, the central bank abandoned the corto and focused only on the operating interest rates, resulting in very few change per year. As shown in the table below, the number of monetary policy rate changes declined substantially after 2008. Using market interest rates, stock indices and foreign exchange rates, the study will determine whether markets are able to better separate the monetary policy news and macroeconomic news components in the announcements. The methodology will include event study to study the changes over time.

■ WA-02

Wednesday, 8:30-10:00 - Bulding A, Room A5

Multicriteria Decision Aid Applications

Stream: Multiple Criteria Decision Analysis
Invited session
Chair: *Athanasios Spyridakos*

1 - Multiple-channel Strategy Selection: A Novel Application of Dominance-based Rough Set Approach
Mladen Stamenković, Aleksa Dokić, Dragan Stojkovic

Existing literature provides ample theoretical foundation for multiple-channel strategy selection. Retailers need a clear-cut take on the roadmap to achieving a specific multiple-channel strategy. A fast-moving customer environment emphasizes the need for a precise, measurable, and easily replicable framework for multiple-channel strategy selection. However, the issue of quantifying the classification process is still not addressed. The idea behind the paper is to address the issue of creating an objective, non-biased method for quantitative classification of retailers according to their multiple-channel strategic modality. This paper aims to combine the multiple criteria decision aiding methodology with the existing theoretical framework for multiple-channel strategic classification. We will use a dominance-based rough set approach to provide a set of decision rules to identify retailers' multiple channel strategy. The main managerial takeaway of the paper is precise multiple-channel implementation guidance. Derived "if-then" decision rules help managers focus on business actions relevant to achieve specific multiple-channel modality. A fully quantified framework also simplifies the optimization process to select appropriate multiple-channel modality for the brick-and-click newcomers.

2 - Using capabilities for aiding policy design.
Nicolas Fayard, Chabane Mazri, Alexis Tsoukias

To a large extent aiding to design public policies consists in introducing elements of rationality (under different forms) within a public decision process. "Rationally speaking", if a policy is expected to have any impact upon the citizens' welfare, it makes sense to try to measure it: as it stands presently and as it could stand under different possible scenarios. However, welfare is a complex issue, implying multiple dimensions and aspects, impacting and being perceived differently among different segments of the society, being distributed unequally among the citizens. Under such a perspective it is unlike that a single figure welfare measurement can be of any utility for effective policy design purposes. We propose to use the Capability Approach (CA) as a theory about how to consider welfare. We suggest a multi-objective mathematical programming framework allowing to develop appropriate decision aiding for public policy design. Our proposal is that the CA could offer a common ground to different stakeholders assessing the impact of a policy to the citizens' welfare, offering a certain number of advantages with respect to other approaches aiming at measuring welfare (although technically more complicated and certainly more expensive to conduct in terms of analysis).

3 - Composite indicators as decision making tools: the joint use of compensatory and non-compensatory schemes
Samira El Gibari, Jose Manuel Cabello, Trinidad Gomez, Francisco Ruiz

Composite indicators are powerful tools for summarizing, focusing and condensing the complexity of our dynamic environment, and their use has become indispensable for managing huge amounts of information. An important aspect to emphasize when constructing composite indicators is the compensatory character among the individual indicators. In general, a fully compensatory scheme provides an overall assessment of the performance of each unit, while a non-compensatory scheme detects the worst single performances. When used in a decision-making framework, the joint consideration of both schemes may, therefore, be helpful. Nevertheless, in the literature, few approaches allow the construction of composite indicators for different compensation degrees. On these premises, the aim of this paper is to illustrate the behaviour of some methodologies that build composite indicators allowing different compensation degrees. We analyse the results provided by each of these methods and which of them provide a more varied complementary information when considering both compensatory and non-compensatory scenarios. An illustrative example is used to visualise the results.

■ WA-03

Wednesday, 8:30-10:00 - Bulding A, Room 3A

Topics in Combinatorial Optimization III

Stream: Combinatorial Optimization
Invited session
Chair: *Heinrich Kuhn*

1 - A reinforcement learning-based operator selection in iterated local search for solving scheduling problems
Maryam Karimi Mamaghan, Patrick Meyer, Mehrdad Mohammadi, Bastien Pasdeloup

Machine learning techniques can be integrated into meta-heuristics for solving combinatorial optimization problems. The main aims of such integration are to improve the quality of the final solutions, increase the robustness of the meta-heuristics, and reduce the computational time. This work develops an iterated local search algorithm exploiting reinforcement learning to select search operators in the resolution of NP-hard scheduling problems. The candidate operators have different exploration/exploitation abilities, allowing the selection algorithm to adaptively select the most appropriate one during the search process, based on the status of the search and the performance history of each operator. Through comprehensive experiments, we demonstrate effective gains in using reinforcement learning rather than a random selection of operators. The results show that our algorithm provides better solutions in terms of optimality gaps and convergence behavior, without imposing significant computational overhead, compared to other meta-heuristics in the literature.

2 - A Hybrid Adaptive Large Neighborhood Search for Vehicle Routing Problems with Location Decisions
Stefan Voigt, Heinrich Kuhn, Markus Frank, Pirmin Fontaine

We present a novel heuristic for a class of Vehicle Routing Problems with Location Decisions based on the recently proposed Hybrid Adaptive Large Neighborhood Search (HALNS). We show that the Location Routing Problem (LRP) and the Multi-Depot Vehicle Routing Problem (MDVRP) can be formulated as special cases of the Two-Echelon Vehicle Routing Problem (2E-VRP) and therefore be readily solved with a single heuristic framework. The HALNS exploits the structure of such two-stage problems, where the first stage (location decision) strongly influences the second stage (routing decision). Once the first-stage decisions are made, the two-stage structure makes it hard to escape local minima in the second stage without allowing for major deterioration of the solution. The HALNS uses a population of solutions generated by an efficient ALNS to overcome this issue. Individuals of this population are subject to a crossover and selection phase, using elements of genetic algorithms resulting in a hybrid heuristic. Computational experiments on several sets of instances from literature show the good performance of the HALNS. The HALNS is on par with heuristics that are dedicated either to the LRP, the MDVRP or the 2E-VRP, showing that generality does not necessarily decrease solution quality. The HALNS especially outperforms all existing pure ALNS implementations on these problem classes, demonstrating the value of hybridization.

■ WA-04

Wednesday, 8:30-10:00 - Bulding A, Room 3B

Routing applications - onsite

Stream: Routing, Logistics, Location and Freight Transportation
Invited session
Chair: *Farzaneh Rajabighamchi*
Chair: *Anne-Laurence Hulot*

1 - An Exact Model for the order picker routing problem in warehouses
Farzaneh Rajabighamchi, Stan Van Hoesel, Christof Defryn

This paper is dealing with the order picker routing problem within a multi-block warehouse layout with several aisles. In the literature, exact algorithms only exist for small warehouses with few cross aisles (typically two or three), while for larger warehouse configurations a series of heuristic and meta-heuristic methods are available. We present a novel pre-processing algorithm for graph reduction by eliminating the extra corner vertices and aisles from the graph of warehouse locations and aisles. This allows us to solve this routing problem with a general TSP solver while significantly reducing running times. The presented method allows us to solve adequately big (more realistic) instances exactly. The algorithm is implemented and evaluated experimentally on a set of problem instances from the literature. The computational results illustrate that the proposed model outperforms existing formulations in terms of simplicity, size, and calculation time. Our mathematical model gives an optimum solution for all the instances, while the network size could be reduced by almost 73% on average.

2 - An Infeasible Space Exploring Matheuristic for the Production Routing Problem
Eleftherios Manousakis, Grigoris Kasapidis, Chris Kiranoudis, Emmanouil Zachariadis

We propose a novel matheuristic algorithm for solving the Production Routing Problem (PRP). The PRP is a hard-to-solve combinatorial optimization problem with numerous practical applications in the field of freight transportation and logistics. A manufacturer is responsible for determining production decisions, as well as the timing and the quantity of replenishment services offered to a set of geographically dispersed customers over a multi-period time horizon. The problem calls for jointly optimizing the production, inventory, distribution and routing decisions. The paper provides a two-phase infeasible space matheuristic algorithm for solving the PRP. The first phase deals with a relaxation of the problem to construct production-distribution plans. In the second phase, these are completed with routing information and optimized via a local search framework which oscillates between the feasible and the infeasible solution space. The framework is equipped with mixed integer programming components for optimally restoring infeasibility and for diversifying the conducted search. Computational experiments demonstrate that the infeasibility space exploration significantly contributes to the quality of the final solutions. The results obtained by the proposed matheuristic out-match the results of state-of-the-art approaches: 594 and 55 new best solutions out of 1440 and 90 instances of two well-established benchmark data sets of small-medium and large instances, respectively.

3 - Dynamic Technician Routing Problem with Stochastic Requests
Dai Trong Pham, Gudrun Kiesmuller

Motivated by the problem faced by many home-attended maintenance service providers, this paper considers the problem of routing and spare-parts planning of a single service technician under a dynamic environment where stochastic information about future requests, such as location and demand for spare-parts, is revealed over time. We designed and tested our computationally-tractable simheuristic based solution approach. The preliminary results show that incorporating stochastic information yield better results, compared to the myopic approach where no stochastic information about future requests is included.

4 - An Iterative Approach for the Mobile Workforce Tactical Scheduling Problem with Frequency Constraints
Anne-Laurence Hulot, Stéphane Dauzere-Peres, Chloe Desdouits, Dominique Feillet

In the context of a mobile workforce, whose employees travel from one client to the next to perform tasks, we define the Mobile Workforce Tactical Scheduling Problem with Frequency Constraints. The goal is to build a plan on several weeks that defines who will perform which task on which day and balances service quality and costs. Previous works on workforce planning and scheduling mainly focus either on the design of teams or on the creation of daily plans, but recent studies raise a need for models that are more accurate and can more easily generalize. In our application context, frequency constraints between tasks that are repeated on different days also urge for a broader view. Scheduling tasks with frequency constraints for a mobile workforce has not been studied much in the literature.

As the workforce is mobile, the tactical plan must also consider travel distances to obtain efficient daily routes. Our approach adapts an iterative heuristic proposed for the Production Routing Problem. In each iteration, a MIP model builds an optimal tactical plan with frequency constraints. Then, the daily routes of each employee are optimized by routing heuristics. This approach finds in less than 2 hours plans that offer very good trade-offs between service costs and quality for real-size instances and highly improves the current straightforward sequential approach.

■ WA-05

Wednesday, 8:30-10:00 - Building Δ, Room Δ105

Public transport I

Stream: Timetabling and public transport
Invited session
Chair: *Pieter Vansteenwegen*

1 - A demand responsive public bus system with express services
Dilay Aktas, Kenneth Sörensen, Pieter Vansteenwegen

In this study, we focus on the morning peak hours where the passenger flows towards a city center are typically much larger than the flows in the opposite direction. We introduce a demand responsive system where express services, away from the city center, are allowed for a single line. Based on the expected demand, it is decided, whether a bus should visit all the stops ahead or skip some of them to take a faster way in the return trip so that it increases the frequency of the service towards the city center. When optimizing this system, it is taken into account that some additional time might be required, before the system can return to its conventional operation. We develop a Mixed Integer Quadratic Program to mathematically model this problem. Due to its complexity, only small-sized problems can be solved optimally. Therefore, we also design a metaheuristic algorithm based on Variable Neighborhood Search that finds high-quality solutions within reasonable time for real-sized instances. The results of the benchmark instances show that the demand responsive system can improve the total passenger travel time with up to 10% compared to the conventional system. We also test the performance of the proposed system on an instance that represents an existing bus line around the city of Leuven and observe that up to 8% of improvement is achieved compared to the conventional system.

2 - The integrated on-demand bus routing problem: combining on-demand buses with a fixed route network
Lissa Melis, Kenneth Sörensen

Even though public bus transport is still largely bound to fixed routes and fixed timetables, technology would already allow for a large-scale shift to on-demand (OD) public transport. In an OD bus system, buses would drive along routes completely determined by the demand of passengers. The on-demand bus routing problem (ODBRP) supports the routing of these buses and combines the dial-a-ride problem with bus stop selection. Given a set of requests for transportation, indicating a passenger's origin and arrival location, as well as his preferred arrival time, the aim of the problem is to (1)assign each passenger to an origin and arrival bus stop within walking distance, and (2)develop a set of bus routes, picking up passengers at their origin stop and delivering them to their arrival stop before their preferred arrival time. The first is called bus stop assignment. We group customers so that the bus can avoid extra stops and detours. This way there is more flexibility for the routing to increase the efficiency. This system would expand the accessibility of public transport but would not be able to replace e.g., metro lines transporting large groups of people. Therefore, we introduce the integrated ODBRP or I-ODBRP. The I-ODBRP schedules ODBRP-requests, but a part of each journey may be carried out by a fixed route service. We will present a heuristic for this problem and determine ways to shorten the computation time by smartly assigning fixed lines and OD buses to requests.

3 - Optimal microscopic train timetabling: a Swiss case study
Marcella Samà, Andrea D'Ariano, Marco Pranzo, Dario Pacciarelli

This work deals with the computation of optimized train timetabling solutions at a tactical level. The problem is modeled using the Alternative Graph (AG), with variables related to train timing, sequencing, and routing decisions. Constraints deal with service intention satisfaction, in terms adherence to the required time windows for the services, plus additional operational constraints dealing with passengers' satisfaction and limited infrastructure, rolling stock, and crew resources. The objective function is focused on minimizing the maximum deviation from the intended list of service intentions. Two solvers are compared: AGLibrary, a state-of-the-art deterministic solver for job shop scheduling problem modelled via the alternative graph, developed by Roma Tre University, and CPLEX, a commercial solver developed by IBM ILOG, which is here used to solve a classical big-M mixed-integer linear-programming formulation of the alternative graph model. This work springs from a collaboration between Roma Tre University and SBB AG, thus the two solvers have been tested on instances derived from local networks of the Swiss railways. For the given computational settings, the state-of-the-art solver outperforms the latter solver, and it can be applied to compute feasible microscopic timetables with acceptable maximum deviations and a compatible computation time.

4 - Enhancing the interaction of railway timetabling and line planning with infrastructure awareness
Alessio Trivella, Florian Fuchs, Francesco Corman

Planning a railway system is done in multiple stages that are typically intractable to optimize in an integrated manner. In this work, we develop a novel iterative approach to jointly tackle two of these stages: line planning and timetabling. Compared to existing approaches that iteratively solve the two problems and ban a whole conflicting line plan when the timetable is found infeasible, our method is able to identify the smallest set of incompatible services accurately. Besides, by efficiently exploiting the available railway infrastructure, our method accounts for all the possible routing options of trains, a feature commonly neglected to preserve tractability but that helps in gaining timetable feasibility. Using real data from a railway company in Switzerland, we find that our approach is: (i) practical for solving real-life instances, (ii) an order of magnitude faster than existing benchmarks, and (iii) able to solve more instances. Our insights shed light on the necessity of considering infrastructure and banning conflicts rather than line plans in the joint line planning and timetabling problem.

■ WA-07

Wednesday, 8:30-10:00 - Building Δ, Room Δ102

DEA applications in education

Stream: Data Envelopment Analysis and Performance

Measurement
Invited session
Chair: *Giovanna D'Inverno*

1 - Efficiency and effectiveness from the perspective of inclusion and fairness: analysis of the EU education systems
Dovilė Stumbrienė, Julius Žilinskas, Rimantas Zelvys, Rita Dukynaitė, Audronė Jakaitienė

Inclusive and equitable quality education is at the top of the agenda of education authorities worldwide. However, frontier-based efficiency studies involving cross-country comparisons of education systems in terms of educational equity are still incipient. This paper elaborates on the concepts of efficiency and effectiveness from the perspective of inclusion and fairness to propose a conceptual framework for education systems. According to the proposed framework, the education system of a country could be optimal, selective, excessive, or deprived. We employed the framework for 26 European countries to illustrate its applicability. The Data Envelopment Analysis approach based on a directional distance function model with both desirable and undesirable outputs was used for measuring the effectiveness and efficiency. The comparison amongst education systems is based on all key-stages of education: early childhood, primary, lower secondary and upper secondary, and tertiary education. The empirical results indicate that European countries do not follow the common policy framework for ensuring inclusion and fairness in their education systems as well as within the country between key-stages. Furthermore, we demonstrate that economic categories such as effectiveness and efficiency have different connotations when applied to education and should be interpreted by considering the peculiarities of national education systems.

2 - School study-programs' performance and their determinants
Anna Mergoni, Kristof De Witte

In this paper we investigate the relationship between student's educational performance in secondary and higher education and the study program attended in secondary education. The data are provided by the Flemish Minister of Education and contain student-level information for the cohort of students born from 1991 to 1996 and attending a secondary school in Flanders. A 'Benefit of the Doubt' composite indicator is constructed to benchmark the study programs and to evaluate them in the best possible light. To individuate possible determinants of the study programs' performances a robust and conditional version of the indicator is also implemented. By conditioning for the socio-economic status of the students, we also avoid the bias caused by the self-selection of students coming from a higher background in specific study programs. Additionally, we investigate the determinants of the school's ability in teaching specific study programs by comparing the educational outcomes for cohorts of students in the same study program.

3 - Educational efficiency across Spanish regions: a comparative analysis beyond the average achievement
Gabriela Sicilia, Jose Manuel Cordero, Rosa Simancas

A quality educational system should be able to improve the average academic achievement among its students and at the same time, to ensure that all of them reach basic educational standards. Hence, an educational system should maximize their students' academic results (efficiency) while minimizing the differences in educational terms among them by compensating the most disadvantaged students (equity). Although both educational dimensions, efficiency and equity, should be simultaneously analyzed, the majority of the existing studies consider these educational targets separately. In this context, this paper aims to include equity measure(s) into the efficiency analysis of the Spanish educational system following a comparative approach. Since the Spanish regional governments are responsible for the educational process and the management of educational resources, the study of the educational system in Spain has only sense at the regional level. To measure educational efficiency, we apply a recent methodological approach proposed by Aparicio and Santín (2018) to PISA 2018 data. This method allows us to estimate and compare the performance of schools from different regions, assuming they use different technology of production. We can compare the technical gap between regions, in order to identify the best performers. The results obtained will bring about, for the first time, a full picture of the regional educational systems considering two key dimensions: efficiency and equity.

4 - Performance-based funding in higher education: An innovative Benefit of the Doubt proposal
Giovanna D'Inverno, Kristof De Witte, Samira El Gibari

This paper presents an innovative performance-based composite indicator to seize funding adjustments in higher education. Performance-based funding systems have become increasingly common across different countries, but a refine tool is needed to ensure an incentive scheme and to grant fairness in the benchmarking procedure along the three well-known missions in higher education (research, teaching and technology transfer). We measure the university performance using a robust and robust restricted benefit of the doubt composite indicator. Based on the obtained indicator, we propose an adjustment of the current funding scheme. The suggested tool leads to two main advantages. First, it encourages universities to perform better to get more funding. Second, the reallocation of resources is assigned to the most promising areas, such that funding is used in the most fruitful way. For the empirical application, we analyse the performance of the Spanish public university system by considering strategic homogeneous groups and a set of indicators related to the three mentioned missions. The evidence confirms that highly specialized universities represent the best practices and points out that specialization pays off.

■ WA-21
Wednesday, 8:30-10:00 - Virtual Room 21

Use of Online Group Support Systems with Problem Structuring Methods

Stream: Soft OR and Problem Structuring Methods
Invited session
Chair: *Colin Eden*
Chair: *Mike Yearworth*

1 - Remote decision-making through a new software combining the Strategic Choice Approach and a Multi-Criteria Decision Analysis
Elena Todella, Isabella Lami

The approach to comparison developed in the Strategic Choice Approach (SCA) aims at describing some areas of concern, considering the implications of alternative courses of action related to the decision problem. Comparison areas, as an evaluation framework in a non-numerical scale, actually leave quite open the interpretation to the discretion of the participants. To undertake the encountered difficulties in evaluating the alternatives, this paper proposes a multi-methodological software application, by integrating the Analytic Hierarchy Process (AHP) with the first two modes of SCA. This software application is applied to a case study, with students in Architecture involved in a remote decision-making process concerning a new School of Architecture at the Politecnico di Torino in Italy, to be placed in an historical complex. The application is based on an experiment composed of two exercises: (i) a first application of the shaping mode and the designing mode of SCA in a traditional way; (ii) a second application through the software, combining the first two modes of SCA with the AHP. In both cases, the online visual platform Miro was at disposal of the students to engage in a remote shared understanding. The aim is to address a new multi-methodological framework combining problem structuring with prioritization and evaluation in a software application, aimed at supporting decision-making processes, even in a fully remote communication and collaboration.

2 - Designing AI research to foster community engagement
Christina Phillips

We will describe attempts to create a human centric design process for an AI project which wanted to engage participants from the Leeds area community. The project proposed using participation in the development of text mining algorithms to better understand messaging about Covid 19 and how it is mutated through dissemination. Problem structuring approaches, in particular Human Centric Analytics was bought in to foster both the engagement and the workshop design process with mixed results. We used multiple online tools including Miro design boards. The work is ongoing.

3 - A Problem Structuring Method implemented using a Group Support System
Mike Yearworth, Leroy White

The Covid-19 pandemic enforced a switch to online teaching for an MBA Programme. This required an innovative solution to implementing group case study work in an online setting with the globally distributed class. An online Group Support System (GSS) was used to support a systems modelling approach, where groups of students were tasked with designing transformational processes to achieve business objectives set for them. We report on the design of the problem structuring method, implementation experience and a preliminary evaluation of the approach. We discuss the need for a GSS that scaffolds the problem structuring methodology, as well as just its implementation.

■ WA-22

Wednesday, 8:30-10:00 - Virtual Room 22

Rational inattention

Stream: Behavioral Operations Management
Invited session
Chair: *Andrei Matveenko*

1 - Sparking curiosity or tipping the scales? Targeted advertising to rationally inattentive consumers
Andrei Matveenko, Egor Starkov

This paper argues, in the context of targeted advertising, that receivers' rational inattention or ability to independently acquire information have a non-trivial impact on the sender's optimal disclosure strategy. In our model, a monopolist has an opportunity to launch an advertising campaign and chooses a targeting strategy – which consumers to send its advertisement to. The consumers are uncertain about and heterogeneous in their valuations for the product, and are rationally inattentive in that they must incur a cost if they want to learn their true valuations. We discover that the firm generally prefers to target consumers who are either indifferent between ignoring and investigating the product, or between investigating and buying it unconditionally. If the firm is uncertain about the consumer appeal of its product, it targets these two disjoint groups of consumers simultaneously but may ignore all consumers in between.

2 - Endogenous social norms: equilibrium and its efficiency
Pavel Ilinov

This paper analyses endogenous social norm formation in the heterogeneous economy with different social groups. We assume that each agent chooses a stochastic choice rule from a finite set of alternatives and facing conformity concerns. Conformity is modeled as disutility of deviating from the endogenous average choice rule. Our main finding is that under the relative entropy cost assumption the resulting interior equilibrium social norm is utilitarian socially optimal. All inefficient corner equilibria are eliminated using myopic dynamic equilibrium selection.

3 - Strategic state pooling
Maxim Senkov, Rastislav Rehak

We consider a Bayesian persuasion model in which the state space is finite, the sender and receiver have state-dependent quadratic loss functions, and their disagreement regarding the preferred action is of arbitrary form. The sender trades off the informativeness of the signal and the revelation of the preference misalignment. We study the pooling structure of the optimal signal. We provide a simple procedure for a partial discovery of that structure based on comparisons of preference misalignment on all pairs of states and a test of higher-order pooling. Our model provides insights into situations in which the sender and the receiver care about two different but connected issues, for example, a political advisor who cares about the state of the economy and a politician who cares about the political situation.

4 - Information asymmetry and fairness concerns
Ummuhan Akbay

We present the results of a human-to-human contracting experiment which investigates the effects of information asymmetry on fairness concerns. We focus on a simple supplier-retailer supply chain where each firm determine their share of the selling price and have their private costs. We compare pricing decisions of the firms under perfect information, one-sided and two-sided asymmetry on the private cost information. Our initial findings show that contrary to earlier literature, suppliers' pricing decisions are not affected by having their private cost known. Yet knowing retailer's private cost leads to the supplier's offering lower than optimal prices. Retailers' make higher than optimal pricing decisions leading to lower than optimal profits. Also retailers lower their prices if they know the supplier has a high private cost. Finally, the contract efficiency is positively affected by retailers' private cost being disclosed to the supplier.

■ WA-23

Wednesday, 8:30-10:00 - Virtual Room 23

Quadratic Assignment and Layout Problems

Stream: Engineering Optimization
Invited session
Chair: *Philippe Codognet*

1 - Solving Challenging Large Scale QAPs with DNN-based Branch-and-bound Method
Koichi Fujii, Naoki Ito, Sunyoung Kim, Masakazu Kojima, Hans Mittelmann, Yuji Shinano, Kim-Chuan Toh

We report our progress on the project for solving large scale quadratic assignment problems (QAPs).

Our main approach to solve QAPs is a parallel branch-and-bound method efficiently implemented on a powerful computer system, using the Ubiquity Generator (UG) framework which can utilize more than 100,000.

Lower bounding procedures incorporated in the branch-and-bound method play a crucial role in solving the problems. To obtain a strong and accurate lower bound, we employ the Lagrangian doubly nonnegative (DNN) relaxation and the Newton-bracketing method developed by the authors' group.

In this talk, we describe some basic tools including the lower bounding procedure and branching rules using the information of primal/dual DNN relaxation. We present some preliminary numerical results on some QAP instances from QAPLIB, including tai30a and sko42 from QAPLIB, which have been solved for the first time.

2 - Workstations layout optimization using machine learning-based human pose estimation and genetic algorithms
Jose Antonio Diego-Mas, Rocío Poveda-Bautista

In assembly workstations and picking stations, workers reach parts from surrounding in a specific order to obtain sets of parts to be used in other processes, sub-assemblies or finished products. An incorrect or deficient layout of the working elements around the worker may result in low performance, health problems and mistakes. This work presents a procedure to automatically optimize the layout of the working areas based on productive and ergonomics criteria. A machine learning-based system estimates the poses of the worker from data obtained from a camera. The system captures the positions of the workers' hands while performing the task. The collected data are used by a genetic algorithm to optimize the layout of the working elements considering the worker movements and the geometric constraints of the problem. Similar previously developed systems used inertial or RGB-D sensors to capture the worker movements. Using a regular camera, this approach simplifies the data acquisition, information analysis and layout design processes.

3 - QUBO and Quantum Annealing for the Quadratic Assignment Problem
Philippe Codognet

The framework of QUBO (Quadratic Unconstrained Binary Optimization) has recently attracted much attention for formalizing combinatorial optimization problems, as QUBO problems are well-suited as input for Quantum Adiabatic Computation and Quantum Annealing, including machines such as the D-Wave computer. Many graph-based combinatorial problems (e.g. Min-Cut, Max-Cut, TSP, etc) have already been expressed in QUBO format and experimented on quantum hardware such as the D-Wave computer, which is well-suited when the underlying graph is sparse. Boolean variables of the QUBO format are indeed directly mapped to the "qubits" of the quantum hardware and the quadratic function to optimize directly leads to the definition of a Hamiltonian to minimized. Implementation of other classical combinatorial optimization problems requiring constraints connecting many variables (e.g. "at most one Boolean is true" within a large set of Boolean variables) is much more rare. It is thus still difficult to assess the performance of Quantum Annealing with respect to classical methods. In this paper, we consider a classical combinatorial optimization problem, the Quadratic Assignment Problem (QAP), and we detail how to express it in QUBO format. We also perform, using instances from QAPLIB, a performance comparison between the solving of this problem with QUBO solvers on classical computer, QUBO solver on quantum hardware (D-Wave) and metaheuristic methods on classical computers.

■ WA-24

Wednesday, 8:30-10:00 - Virtual Room 24

Linear Programming and Large Scale Optimization

Stream: Continuous optimization (contributed)
Contributed session
Chair: *Mohammadhossein Mohammadisiahroudi*
Chair: *Eirini Nikolopoulou*

1 - The Benders by batch algorithm: design and stabilization of an enhanced algorithm to solve multicut Benders reformulation of two-stage stochastic programs
Xavier Blanchot, Francois Clautiaux, Boris Detienne, Aurélien Froger, Manuel Ruiz

We introduce a new exact procedure to solve two-stage stochastic linear programs. Assuming that the probability distribution is defined by a finite number of scenarios and that first-stage and second-stage variables are continuous, we propose to not solve all the subproblems at each iteration of Benders decomposition algorithm. This idea has already been studied in the literature but the proposed algorithms either need particular assumptions on the structure of the alea, or do not guarantee the optimality of the solution. We present here an exact algorithm, without any assumptions on the structure of the subproblems.

Our method, the Benders by batch algorithm, relies on a partition of the subproblems. We first propose a new stopping criterion for Benders decomposition based on a sequential evaluation of batches of subproblems. Then we develop a framework with this stopping criterion. For each evaluated first-stage solution, the batches are sequentially solved until the first-stage solution is proven either optimal, or non-optimal using our criterion.

We also propose two stabilization techniques for our algorithm, as classical stabilizations such as in-out stabilization or bundle method cannot be directly applied in our framework. We finally report an extensive numerical study based on large-scale instances from the literature. We show an average of around 90% of time saving compared to best classical Benders implementation with stabilization.

2 - A segmentation rule to determine areas of potential binding and non-binding constraints in LP problems
Eirini Nikolopoulou, George S. Androulakis

A new effort for both dimension and iteration reduction of LP problems is presented. This effort is based on the segmentation of the area that is prescribed from the constraints of the problem into two parts: the high chance area of non-binding constraints and the area of potential binding constraints. The ulterior aim is to find a discriminant rule to determine areas of binding and non-binding constraints. For this purpose, the cosine of the angle between the vectors of the coefficients of the constraint and the objective function of the problem and the ratio of the right handed coefficient and the sum of the coefficients of the corresponding constraint are used. The rule is based on the outcomes from the graphical plot between the cosine and the ratio. It is applied in more than 1500 large scale LP problems, where the number of constraints is about 10-15 times larger than the number of variables and it is applicable for LP problems with positive or zero coefficients, as well as for LP problems with positive and negative objective coefficients. The numerical analysis revealed that the method is about 90% - 95% accurate in identifying the two areas. Furthermore, the method contributes to a reduction, on average, of 30% of the size of the problems regarding the number of constraints, plus a reduction, on average, of 30% of the number of Simplex iterations needed. A detailed example, the general numerical results and the plots of numerical experiments are also presented.

3 - An Inexact Feasible Interior Point Method for Linear Optimization with High Adaptability to Quantum Computers
Mohammadhossein Mohammadisiahroudi, Ramin Fakhimi, Tamás Terlaky

Exploring the opportunities offered by quantum computing to speed up the solution of hard optimization problems is a hot research area. To have a quantum speed-up for continuous optimization methods, Quantum Linear System Algorithms (QLSAs) are applied to solve the Newton systems inside Interior Point Methods (IPMs). Since QLSAs inherently produce inexact solutions, we can only use Inexact variants of IPMs. Existing IPMs with inexact Newton direction are infeasible methods because inexactness leads to infeasibility. In this research, an Inexact-Feasible IPM (IF-IPM) is proposed for Linear Optimization problems using a novel system that produces inexact but feasible steps. The proposed IF-IPM has similar iteration complexity to the best exact IPMs. We also discuss how QLSAs can be used to solve the novel system efficiently and develop a Quantum IF-IPM with better total complexity than the best bound for IPMs. The IF-IPM is implemented with both classical and quantum solvers to investigate their efficiency in computational practice.

■ WA-25

Wednesday, 8:30-10:00 - Virtual Room 25

Applications of Robust and Stochastic Optimization

Stream: Stochastic and Robust Optimization
Invited session
Chair: *Milos Kopa*

1 - Food Banking Network Design under the Risk of Disruption
Suyog Nigudkar, Sachin Jayaswal, Ankur Sinha

Hunger is the biggest challenge faced by developing countries like India, where the FAO estimates nearly 190 million people are undernourished. As part of an initiative to handle this challenge, various nations establish food banking networks. Such foodbanks cater to the daily nutritional demands of a large section of the food insecure population, and hence the network must perform efficiently at all times. However, catastrophic events like cyclones, floods, earthquakes, etc., or failure of some facilities may disrupt the food banking network affecting millions of people. Hence, it is essential to consider such disruptions at the design phase to build a more robust food banking network. In this article, we design a food banking network that can perform economically under normal circumstances and minimize the worst-case losses under disruptions. We formulate the problem as a tri-level defender-attacker-defender Stackelberg game between a network designer (leader) and a hypothetical adversary (follower). The consideration of a hypothetical rational adversary enables the network designer to prepare against the worst-case disruption. We propose a Penalty and a Dual based approach to solve the lower bi-level problem and a Super Valid Inequality (SVI)- based cutting plane approach to solve the tri-level formulation. We conduct detailed computational studies on the Food Banking Network in the US and design the Indian Food Banking Network (IFBN) that is still at a nascent stage.

2 - Vehicle Routing Problem with time windows and stochastic travelling times: stochastic programming and simheuristics
Adela Pages Bernaus, Virna Ortiz-araya, Nuria Nievas Viñals

Realistic applications of the vehicle routing planning demands to account for characteristics such as time windows and to consider stochastic parameters on top of other constraints such as vehicle capacity limits. In the literature, there exists several approaches to address the solution of such problems. In this work we compare two solution approaches: the solution of a Stochastic Programming model and a simheuristic approach. A mathematical approach works well for small instances and allows to verify the solutions found with the simheuristic approach. Simheuristics is a simulation-optimization type of heuristics specialized to solve combinatorial problems with stochastic parameters.

Both approaches have been tested on realistic instances aroused from the delivery of fresh products. The application modelization together with the solution methodologies will be presented and compared.

3 - Multi-objective optimization of multi-microgrid power dispatch under uncertainties using interval optimization
Shungen Luo

The microgrid technology, which can dispatch power independently, is an effective way to increase the efficiency of energy utilization meanwhile develop and utilize the clean and renewable energy. However, the power generation of a single microgrid is unstable, because it is greatly affected by the external environment. Therefore, the development and application of the multi-microgrid system have gradually drawn various countries' attention. In order to minimize the operating cost and gaseous pollutant emissions of the multi-microgrid system, which is composed of renewable energies and electric vehicles and so on, this paper builds a 24 hours day-ahead multi-objective complex constrained optimization model, using interval optimization to model uncertainties of renewable energies. In view of the model characteristics, the metaheuristic strategies about initialization and repair of solution are designed. Meanwhile, the fuzzy membership degree and Chebyshev function are used in parallel to decompose the multi-objective optimization problem, thus a multi-objective evolutionary algorithm based on hybrid decomposition (MOEA/HD) is constructed. Finally, the effectiveness of the metaheuristic strategies can be verified by analyzing the simulation results in this paper. Moreover, the results prove that the MOEA/HD is more efficient, which can get a higher-quality Pareto optimal solution set when compared to other algorithms.

4 - A Simple Method for Robustness Analysis of Non-degenerate Optimal Basic Solutions in Linear Programming Problems with Fuzzy Objective Coefficients
Zhenzhong Gao, Masahiro Inuiguchi, Carla Margarida Saraiva Oliveira Henriques

We propose an approach for robustness analysis of non-degenerate optimal basic solutions in inexact linear programming problems, which have fuzzy objective coefficients. As the coefficients in the objective function are not known precisely, we only have the information roughly by their possible ranges described by fuzzy numbers. For generality, we consider several fuzzy numbers in different membership functions. We start with the simplest structure, called non-interactive triangular ones. Then we consider the non-interactive general one, and finally to interactive oblique one, the hardest one. To deal with the non-existence of a necessarily optimal solution, we propose the degree of necessary optimality, representing the robustness degree of a non-degenerate basic solution. We show that one can solve the degree by direct algorithms utilizing the tolerance analysis methodology without iterative procedure. Finally, we consider the fuzzy coefficients with non-linear membership functions and show that one can use the bisection method to solve.

■ WA-26

Wednesday, 8:30-10:00 - Virtual Room 26

Nonlinear Optimization Theory and Methods

Stream: Nonlinear Optimization
Invited session
Chair: *Yaohua Hu*
Chair: *Zhilong Dong*

1 - Equipping the Barzilai-Borwein gradient method with two-dimensional quadratic termination property
Yu-Hong Dai

Since its proposition in Cauchy (1847), one milestone work along the gradient method is the Barzilai-Borwein (nonmonotone) method (1988), while another significant work is the Yuan stepsize in (2006), which leads to the appearance of the efficient Dai-Yuan (monotone) gradient method (2005). In this talk, a new gradient stepsize will be delivered at the motivation of equiping the Barzilai-Borwein method with two-dimensional quadratic termination property. A remarkable feature of the new stepsize is that its computation only depends on the Barzilai-Borwein stepsizes in two previous iterations, without the need for exact line searches and Hessian, and hence it can easily be extended for nonlinear optimization. By adaptively taking long Barzilai-Borwein steps and some short steps associated with the new stepsize, we develop an efficient gradient method for unconstrained optimization. The proposed method is further extended for box-constrained constrained optimization and singly linearly box-constrained optimization by incorporating nonmonotone line searches and gradient projection techniques. Numerical experiments demonstrate that the proposed method outperforms the most successful gradient methods in the literature. This is a joint work with Yakui Huang and Xinwei Liu.

2 - On some extended mixed integer optimization models of the Eisenberg-Noe model in systemic risk management
Zhilong Dong

The Eisenberg and Noe (EN) model has been widely adopted in the systemic risk management for finan- cial networks. In this paper, we propose a unified EN (U-EN) model, which incorporates both liquidation and bankruptcy costs. We show that the U-EN model is polynomial-time solvable and develop an efficient greedy algorithm to solve it. Then we consider identifying the optimal bailout strategy based on stress testing background and propose a binary EN model with bailout budget constraint (B-EN-B). The B-EN-B model is shown to be NP-hard. We present analysis on the parameter selection and design some preprocessing pro- cedures correspondingly. A sequential coefficient strengthening algorithm is designed to solve the B-EN-B model. Global convergence of the algorithm is established. Moreover, we show that the systemic risk level obtained from the B-EN-B model can be used as a precaution for the social planner. Experiments based on both simulated data and data from the Chinese listed banks' network are reported to demonstrate the efficiency of the proposed algorithms.

Authors: Zhi-Long Dong, Jiming Peng, Fengmin Xu and Yu-Hong Dai

3 - An Efficient Approach for Projection onto the Nonconvex l_p Ball
Hao Wang

This paper primarily focuses on computing the Euclidean projection of a vector onto the l_p ball in which p is less than 1. Such a problem emerges as the core building block in statistical machine learning and signal processing tasks because of its ability to promote sparsity. However, efficient numerical algorithms for finding the projections are still not available, particularly in large-scale optimization. To meet this challenge, we first derive the first-order necessary optimality conditions of this problem using Frechet normal cone. Based on this characterization, we develop a novel numerical approach for computing the stationary point through solving a sequence of projections onto the reweighted l1-balls. This method is practically simple to implement and computationally efficient. Moreover, the worst-case complexity is derived under mild conditions. Numerical experiments demonstrate the efficiency of our proposed algorithm.

4 - Lipschitz-like property relative to a set and the generalized Mordukhovich criterion
Xiaoqi Yang

In this paper we will establish some necessary condition and sufficient condition respectively for a set-valued mapping to have the Lipschitz-like property relative to a closed set by employing regular normal cone and limiting normal cone of a restricted graph of the set-valued mapping. We will obtain a complete characterization for a set-valued mapping to have the Lipschitz-property relative to a closed and convex set by virtue of the projection of the coderivative onto a tangent cone. Furthermore, by introducing a projectional coderivative of set-valued mappings, we establish a verifiable generalized Mordukhovich criterion for the Lipschitz-like property relative to a closed and convex set. We will study the representation of the graphical modulus of a set-valued mapping relative to a closed and convex set by using the outer norm of the corresponding projectional coderivative value. For an extended real-valued function, we will apply the obtained results to investigate its Lipschitz continuity relative to a closed and convex set and the Lipschitz-like property of a level-set mapping relative to a half line.

■ WA-27

Wednesday, 8:30-10:00 - Virtual Room 27

Data Science and Analytics - Applications in Transportation

Stream: Data Science and Analytics (contributed)
Contributed session
Chair: *Luigi De Giovanni*

1 - Route based Driving Range Prediction of Electric Vehicles by using Static and Dynamic Data
Hilal Yilmaz, Betul Yagmahan

Accurate prediction of the remaining driving range of electric vehicles (EVs) is crucial for drivers considering taking long journeys. Many factors such as elevation, weather, and driver behavior have significant effects on the driving range that should be taken into account when estimating the driving range. Thanks to the developments in the information technology field, it is now possible to gather online data from various sources. Hence, the remaining driving range prediction can be improved using the real-time information collected for a specific route. The aim of this work is to predict the remaining driving range of an EV for a pre-determined route. Therefore, we used real driving data collected from a specific EV from various drivers in the US and Europe. The data contains static features such as the driver ID, the weather, vehicle and passenger weight, date of the trip, and time series data of the EV that show the speed (m/s), acceleration (m/s2), driving distance (m), elevation (m) and power (kW) for each timestamp. A deep neural network approach that uses both static features and time-series data is developed to improve the prediction results. The proposed approach is then compared with the predictions obtained without using static data. According to the results, the proposed approach has the capacity to provide highly accurate predictions.

2 - Maintenance Add-on to Logistics: Data fusion for a reduced logistics footprint
Dino Spirtovic, Rob Brink

Aviation companies use prognostics for logistics and maintenance, but data fusion between these domains is rare. Supply chains have short planning horizons and vendors store extra spare parts at strategic locations for security of delivery. However, this approach results in additional cost and large logistics footprints. Accurate and timely predictions of failures and failure modes enable just in time spare parts delivery and efficient parts repair. Component histories, flight data and maintenance records are combined to enrich data. Failures are predicted through binary classification. Supervised and unsupervised learning approaches are evaluated to obtain diagnostics models. Multi-echelon models are developed for network stock optimisation. Failure of a shop replaceable component in a main landing gear and a valve is predicted. Average accuracy and recall for the former is 75%, whereas the latter scores 60%. Multi-echelon models calculate significantly reduced network stock and repair lead time with 3 days warning time, while maintaining an aggregate service level of 95% and taking up to 10% false negatives into account. Conclusions are that: 1) material condition data is required for accurate diagnostics and prognostics; 2) accuracy and timeliness of failure predictions are key drivers of network stock; and 3) data-driven failure diagnostics, combined with multi-echelon models and a logistics management system, reduce lead times and cost of repairs.

3 - A Deep Imitation Learning Approach for Solving the E-commerce Box-Sizing Problem
Shanthan Kandula, Srikumar Krishnamoorthy, Debjit Roy

The box-sizing problem is concerned with finding the optimal combination of packaging box sizes that covers all the product SKUs hosted on an e-commerce platform while maximizing the space utilization of boxes. The problem is crucial to e-commerce companies since using an optimal set of boxes reduces the need to use additional protective material and results in the efficient usage of transportation capacity.

Nevertheless, determining an optimal combination of boxes for covering thousands of product SKUs is challenging. This paper proposes a scalable machine learning approach to solve the box-sizing problem. In particular, the approach works in three steps. In the first step, SKUs are modeled as data points in 3D space, and an unsupervised learning task is formulated to determine the initial solution. With the initial solution as the root node, a search tree is developed, and an ensemble of neural networks is trained to imitate the greedy branching decisions with respect to n-step rollouts in the second step. In the third step, a tree search is carried out from the root node, where branching decisions are made based on the rollouts simulated by neural network policies. The proposed approach is validated on a large dataset collected from a leading e-commerce platform. Results indicate the superiority of the proposed approach.

4 - Mining optimal trajectories for the Air Traffic Flow Management Problem
Luigi De Giovanni, Martino Echerle, Guglielmo Lulli

The objective of the Air Traffic Flow Management Problem (ATFM) is to assign 4D trajectories to flights to guarantee both safe operations and efficient use of airspace. Several methodologies have been proposed to manage ATFM operations, and Integer Linear Programming (ILP) proved to be one of the most common. In this talk, we present an ILP model that assigns a trajectory with a possible ground delay to each flight. For each flight, the set of relevant trajectories is extracted from air traffic data repositories using data analytics tools. Because the number of possible trajectories can be extremely large, we propose a heuristic that combines simulated annealing with machine learning. The heuristic iteratively solves the ILP model restricted to subsets of variables (representing trajectory-ground delay pairs) that change at each iteration. At each step, a tree classifier guides a random selection of relevant variables that are likely to improve the current solution. The tree classifier considers features related to both variables and the current solution, according to a preliminary training on reduced size instances. Results are compared to a heuristic based on column generation and show the ability of the proposed method to effectively solve realistic instances by sensibly reducing running times while preserving the quality of the solutions.

■ WA-28
Wednesday, 8:30-10:00 - Virtual Room 28

Machine Learning and Optimization: new challenges, applications and objectives I

Stream: Mathematical Optimization and Data Science
Invited session
Chair: *M. Asuncion Jimenez-Cordero*

1 - Multi-objective Optimization for Counterfactual Explanations
Jasone Ramírez-Ayerbe, Emilio Carrizosa, Dolores Romero Morales

Post-hoc explanations of machine learning models are crucial to be able to understand and explain their behaviour, and thus ensure transparency and fairness. An effective class are counterfactual explanations, i.e. minimal perturbations of the predictor variables to change the prediction for a specific instance. In this talk, we will provide a multi-objective mathematical formulation for different state-of-the-art models used for the prediction, including tree ensemble classifiers and linear models. A running example with real-world data will be used to illustrate our method.

2 - A stochastic multi-scale model of Francisella tularensis infection
Martin Lopez-Garcia

In this work, we present a multi-scale model of the within-phagocyte, within-host and population-level infection dynamics of the bacteria Francisella tularensis. Our multi-scale model incorporates key aspects of the interaction between host phagocytes and extracellular bacteria, accounts for inter-phagocyte variability in the number of bacteria released upon phagocyte rupture, and allows one to compute the probability of response, and mean time until response, of an infected individual as a function of the initial infection dose. A Bayesian statistical approach is applied to parameterize both the within-phagocyte and within-host models using infection data. Finally, we show how dose response probabilities at the individual level can be used to estimate the airborne propagation of Francisella tularensis in indoor settings (such as a microbiology laboratory) at the population level, by means of a deterministic zonal ventilation model.

3 - Multilevel training startegies for artificial neural networks
Elisa Riccietti, Henri Calandra, Serge Gratton, Xavier Vasseur

We propose a family of multilevel optimization methods to solve large-scale minimization problems arising from the training of artificial neuralnetworks. The proposed methods aim at exploiting the structure of the neural network to build a sequence of problems of decreasing dimension, approximating the original one. This is much in the spirit of classical multigrid methods, with the exception that the problems at handdo not have an obvious geometrical structure to exploit, as the variables subject to optimization are the weights and biases of the network. We propose then the use of algebraic multigrid tools to explore the structure of the neural network and to build a hierarchy of coarse problems and operators. The knowledge of such hierarchy is exploited to reduce the major cost per iteration of classical optimization methods, that is the stepcomputation, allowing for a faster training process. We consider as a test problem the solution of Partial Differential Equations (PDEs). The learning process is formulated as a least-squares problem, based on the minimization of the nonlinear residual of the equation, which is solved by a multilevel Levenberg-Marquardt (LM) method.

4 - Improving the performance of machine learning in the solution of MILPs
M. Asuncion Jimenez-Cordero, Juan Miguel Morales, Salvador Pineda Morente

Solving large-scale Mixed Integer Linear Problems (MILP) is well known to be a challenging task. To alleviate their computational burden, several works in the literature have proposed Machine Learning techniques to identify and remove constraints. However, all these techniques report that a non-negligible percentage of the obtained solutions are infeasible since they violate some of the removed constraints. This talk presents an offline-online strategy that improves the quality of the available data to significantly reduce the number of infeasible solutions. By linking Mathematical Optimization and Machine Learning, our approach leads to substantial performance improvements in terms of feasibility and computational time, which we demonstrate through synthetic and real-life MILP problems.

■ WA-29
Wednesday, 8:30-10:00 - Virtual Room 29

DSS - Applications - 2

Stream: DSS
Invited session
Chair: *Jason Papathanasiou*

1 - Solving a heterogeneous fleet multi-compartment vehicle routing problem: A case study
Simos Efthymiadis, Nikolaos Liapis, George Nenes

Vehicle Routing Problem (VRP) is a complex optimization problem in the field of supply chain management, especially in the Oil & Gas sector. Due to the rising cost of fuel, effective planning of transportation routes has become a crucial success factor for distribution companies, increasing operational efficiency as well as the corresponding service level. In this study, we present an optimization model to solve a heterogeneous fleet multi-compartment vehicle routing problem (MCVRP), a variant of the conventional vehicle routing problem (VRP). Real data is obtained from a medium size oil distribution company, operating in Greece and incorporates over twenty petrol stations located in northern Greece served from a central oil depot using a fleet of various multi-compartment tanker trucks. The main objective of this research is to design an optimum set of routes minimizing distance and truck operating costs. The multi-compartment vehicle routing problem (MCVRP) with a heterogeneous fleet of vehicles is modeled as a Mixed-Integer Linear Programming (MILP) problem and the proposed solution determines the number of assigned vehicles, the planning of daily routes, and the allocation of different fuels to vehicles compartments, while satisfying customer demand following the specific requirements as detailed in the Carriage of Dangerous Goods (ADR) Regulations.

2 - Transportation resilience optimization form an economic perspective at the pre-event stage
Tingting Zhang, Chence Niu, Edward Robson, Divya Nair, Vinayak Dixit

Recently, natural or man-made disasters affected or even interrupted the transportation system while brought in greatly huge economic losses than ever. However, since COVID-19 has increased the costs and cut the income of the local government, it is not hard to imagine that the local governments confronting funding reduction struggle with limited budgets allocated to the transport authorities. This study tackles the problem of road pre-investment with the objective of improving the resilience of the traffic system by formulating it as a bi-level optimization model that minimizes the network economic-based resilience measurement (NERM) in disruption scenarios. In this research, the Shapley value is used to determine the vital links and analyze the vulnerability of the road network. The computable general equilibrium (CGE) model is applied to capture the social welfare and economic impacts, which are treated as the inputs of NERM. The heuristic approach is used to reach a local optimal solution for a real-life network of Sydney. Results will help practitioners make more informed decisions.

3 - Spline-rule ensemble classifiers for comprehensible marketing and risk analytics
Koen W. De Bock

Classifiers in marketing and business analytics should deliver comprehensible and justifiable models to assess their compliance with common sense and business logic, guarantee their acceptance throughout the organization and facilitate deployment. A promising ensemble classification algorithm that was shown to reconcile performance and comprehensibility are rule ensembles. This talk focuses on spline-rule ensembles (SRE) which complement rules and linear terms with smooth functions. SREs pursue a more natural accommodation of non-linear effects of individual features. Applications and model extensions in bankruptcy prediction and customer churn prediction are presented to illustrate the technique's versatility, accuracy, and interpretability.

4 - Integrated Decision Support System for Rich Vehicle Routing Problems
Gwénaël Rault, Philippe Lacomme, Marc Sevaux

Recent economic and environmental constraints push supply chain management systems to adopt closed-loop supply chain operating modes that have to address very complex problems including the end-user quality of services, environmental considerations, and daily transportation time variations. Relevant and challenging research areas require a proper coordination between the data provider software (Transport Management Software) and the operational research tool in charge of trip definition.

This abstract proposes a decision support system applied to the Vehicle Routing Problem able to tackle very large instances with real-life constraints. Our contribution is to propose an architecture that handle both static resolution prior to the completion of routes and update them in a dynamical context during their completions. This is implemented through a REST based API using numerous state-of-the-art operational research methods. Moreover, this system in used in practice by the Mapotempo company.

■ WA-30

Wednesday, 8:30-10:00 - Virtual Room 30

Mixed Integer Linear Programming for transportation problems II

Stream: Mixed Integer Linear Programming
Invited session
Chair: *Carlo Mannino*
Chair: *Giorgio Sartor*

1 - A MILP model for quasi-periodic strategic train timetabling
Giorgio Sartor, Carlo Mannino, Lukas Bach, Thomas Nygreen

In railways, the long-term strategic planning is the process of evaluating improvements to the railway network (e.g., upgrading a single track line to a double track line) and changes to the composition/frequency of train routes (e.g., adding 1 train per hour along a certain route). The effects of different scenarios, that is combinations of infrastructure improvements and route changes, are usually evaluated by creating new feasible timetables followed by extensive simulation. Strategic train timetabling (STT) is indeed the task of producing new tentative timetables for these what-if scenarios. Unlike the more classic train timetabling, STT can overlook some operational aspects, such as crew and rolling stock scheduling. On the other hand, each strategic timetable is likely to be very different from previous ones, hindering the common and effective practice of using existing timetables to warm start the solution process. We introduce the concept of quasi-periodic timetables, that are timetables where certain subsets of trains need to start at almost (rather than precisely) the same minute of every period. Not only quasi-periodic timetables offer greater flexibility than their perfectly-periodic counterpart, but they may also require less computation time (despite having more variables and constraints). We describe a MILP model for strategic quasi-periodic train timetabling and we present computational results for an important line in Norway on 8 different scenarios.

2 - A logic Benders decomposition for microscopic railway timetable planning
Florin Leutwiler, Francesco Corman

Railway timetable planning is one of the key factors in the successful operation of a railway network. The timetable must satisfy all operational restrictions at a microscopic representation of the railway network, while providing the maximal possible transportation capacity for passengers and freight. Railway timetable planning has been proven to be an NP-Hard problem, which imposes a significant challenge when planning for dense, large-scale networks, e.g., those of the many countries in Europe. For the problem of microscopic railway timetable planning we propose a new logic Benders decomposition approach and contribute with an algorithm of improved scalability compared to a standard MILP approach. We design a novel type of logic Benders cut, valid for subproblems within the Benders decomposition, which are equivalent in constraints to a generic timetable planning problem, proposing a generalization compared to the state of the art. The novel type of cuts permits a geographic decomposition of the timetable planning problem, where we identify areas of high network density as the subproblems in the Benders decomposition. We effectively extend techniques from the field of Boolean satisfiability solving

(SAT) for the computation of the novel logic Benders cuts for local areas. Experiments on parts of the network from the Swiss Federal Railways show promising scalability improvements of the new approach in comparison with a standard MILP approach solved by a commercial solver.

3 - MILP-based Algorithms for the Generalized Train Unit Shunting Problem
Paola Pellegrini, Franck Kamenga, Joaquin Rodriguez, Boubekeur Merabet, Bertrand Houzel

In passenger railway transportation, train-units perform sequences of services. Service changes typically occur in stations. Here, the train-unit re-utilization time can be largely different. On the one hand, a somehow immediate re-utilization may be carried out: the concerned train-units typically remain parked at the station platform. On the other hand, several hours may pass between a service and the following one: train-units are typically moved to specific yards connected to the station. They are called shunting yards. Here, train-units must be parked, can be subject to maintenance operations, and can be coupled and uncoupled to fit the requirements of the next service. The Generalized Train Unit Shunting Problem (G-TUSP) consists in managing what happens in shunting yards: delays and maintenance operations cancellation are minimized as well as the duration of shunting movements and the number of coupling or uncoupling operations, while satisfying operational constraints and timetable requirements. Here, we propose different algorithms based on mixed-integer linear programs (MILP) to solve the G-TUSP. They consider various integration approaches to deal with its main sub-problems: Train Matching, Track Assignment, Shunting Routing and Shunting Maintenance Problem. We test these algorithms on scenarios based on Metz-Ville station in France. The experiments highlight the interest of integrating specific sub-problems depending on the situation to be tackled.

4 - Rescheduling Trains with Speed Target Recommendation on Railway Lines Equipped with ATO System
Zhengwen Liao, Lingyun Meng, Jianrui Miao, Jianpeng Dai, Yihan Tan

Railway lines equipped with automatic train operation (ATO) system allow more elaborated train rescheduling, including reordering, retiming the arrival and departure time at stations, as well as the train speed profiles. Therefore, the train rescheduling algorithm is required to provide the recommended speeds to the ATO system while specifying the rescheduled arrival and departure times. For this purpose, we model the train rescheduling problem with recommended speed decision using a three-dimension network, namely time-space-speed, followed by a network flow-based MILP model solved by Lagrangian relaxation solution approach. For reducing the scale of the high dimension networks, a time-space-state network reduction technique associated with the preference of train driving strategies is applied to eliminate the redundant arcs. A real-time blocking time calculation with respect to the different train speeds is embedded in the algorithm framework to increase the accuracy of train conflict avoidance. The case study on Beijing-Zhangjiakou ATO high-speed railway shows the performance of the proposed algorithm by three objectives, namely minimizing the average delay of passengers, minimizing the total amount of delayed trains, minimizing the delay of trains.

■ WA-31

Wednesday, 8:30-10:00 - Virtual Room 31

Scheduling and Networks

Stream: Network Optimization
Invited session
Chair: *Tristan Becker*

1 - Shrinking of support graphs in cycle problems
Gorka Kobeaga, Maria Merino, Jose A. Lozano

In this work, we extend the shrinking techniques developed in the context of the Travelling Salesperson Problem for cycle problems. The efficient application of the considered techniques has proved to be essential in the Travelling Salesperson Problem when solving large size problems by Branch-and-Cut, and this has been the motivation behind this work. We prove the validity of the Padberg-Rinaldi general shrinking rules and the Crowder-Padberg subcycle-safe shrinking rules.

The proposed techniques are empirically tested in 24 subcycle elimination problem instances generated by solving the Orienteering Problem (involving up to 15112 vertices) with Branch-and-Cut. The experiments suggest the relevance of the proposed techniques for cycle problems. The obtained average speedup for the subcycle separation problems in the Orienteering Problem when the proposed techniques are used together is around 50 times in medium-sized instances and around 250 times in large-sized instances.

2 - A New Approach to Model and Solve the Hierarchical Interval Schedule Problem with Machine Availibility
Zhang Jiarui

Hierarchical Interval Schedule Problem with Machine Availability (HISP-MA) is a problem to find the maximal matching schedule, in which given heterogeneous job intervals should be assigned to given heterogeneous machines intervals without job intervals' overlap, reuse or interruption. We model the HISP-MA problem by an Origion and Destination Integral Multicommodity Flow Model (ODIMCF) based on Directed Acylic Gragh (DAG). Compared with the traditional Graph Coloring Model (GC) based on Interval Graph, in cases with less discrete time units, the ODIMCF model significantly outperforms GC in both the model size and the solution efficiency. In order to solve the more complicated HISP-MA problems in the real world, we bring up the State-DAG togather with two Multicommodity Flow Decompsition Model (namely MCF-1, MCF-2) to decompose the HISP-MA to several easily-solved subproblems. Then, we combine the ODIMCF with MCF-1 and MCF-2 to generate a decompose and solve algorithm for large scale HIPS-MA problems. Finally,we test the algorithm with a randomly generated dataset of the real-world locker-express intervals matching situation. The numerical experiment shows that the algorithm can stably get the best schedule of HISP-MA problems with 3500 job intervals and 1000 machine intervals within 60 seconds.

3 - Developmental Cost Optimisation of Water Distribution Networks
Saumya Goyal, Om Damani, Ashutosh Mahajan

We study the problem of cost optimisation for cyclic water distribution networks. These networks contain a single source node and multiple demand nodes with residual pressure constraints. The presence of cycles in the network causes indeterminate flow value and direction through most links in the network. While these quantities are deterministic and easy to compute for an acyclic network, this makes the problem considerably hard and nonconvex for cyclic networks. In this work we provide the least possible development cost configurations for piping of each link in the network. We explore three optimisation formulations to solve the problem and compare their efficacy on the basis of solutions obtained through a local optimisation solver. In addition, we note that despite the presence of link cycles in the network, flow through the network is necessarily acyclic. We further note that very few of these acyclic orientations are actually optimal, or even feasible. We thus explore the feasibility and benefit of enforcing such orientations explicitly as a constraint. Finally, we propose a parallel link formulation that models flow in each link as two separate flows with opposing directions. This allows the solver to implicitly exploit the notion of orientations by penalising exploration of flow directions that perform worse locally, through mere physical sanity constraints. The approach is thus not only more tractable but also more beneficial for use with bigger networks when compare

4 - A General Algorithmic Framework for Rotating Workforce Scheduling
Tristan Becker, Maximilian Schiffer, Grit Walther

Rotating workforce scheduling remains a central planning task in many industries as efficient staff scheduling can ensure a consistent and fair work schedule for employees. Against this background, we propose a general algorithmic framework for rotating workforce scheduling. We develop a graph representation that allows modeling a schedule as an Eulerian cycle of stints, which we then use to derive a compact problem formulation in terms of the number of employees. We develop a general branch-and-cut framework that solves rotating workforce scheduling in its basic variant and several additional problem variants relevant in practice. These variants comprise maximizing the number of free weekends, minimizing the number of employees, ensuring a minimum number of weekly rest periods, and finding multiple schedules. Our computational studies show that the developed framework constitutes a new state of the art for rotating workforce scheduling. For the first time, we solve all 6000 instances of the status quo benchmark for rotating workforce scheduling to optimality with average computational times of 0.07 seconds and a maximum computational time of 2.53 seconds. These results improve upon the computational performance of existing methods by orders of magnitude. Our algorithmic framework is robust and shows consistent computational performance across all studied problem variants.

■ WA-32

Wednesday, 8:30-10:00 - Virtual Room 32

Urban and Territorial Planning in MCDA 2

Stream: Multiple Criteria Decision Analysis
Invited session
Chair: *Isabella Lami*

1 - A multi-criteria model to support shading devices selection in a real office building
Giulia Crespi, Federico Dell'Anna, Maria Cristina Pinto, Cristina Becchio

Solar shading contributes effectively to energy savings, especially if combined with effective management and control strategies. This category identifies all devices that allow to respond dynamically to the variations of solar stresses towards the internal environment. Indeed, their efficient design helps maximizing thermal gains in winter and reducing loads in summer, especially in buildings with big transparent areas. In addition, shading systems can improve occupants' visual and thermal comfort. Despite the financial barriers that still hinder their diffusion, in EU diverse incentive mechanisms are in place, which may push it. This is true in Italy, where, thanks to the "2020 Relaunch Decree", energy efficiency interventions in buildings, including the installation of shading systems, can access a 110% tax deduction. There exist several factors that can influence the choice of shading systems, due to potential conflicts from economic, financial, environmental, social, and energy standpoints. To overcome this obstacle, a decision-based framework was designed and tested on a real office building in Italy. Different shading devices, coupled with management and control strategies, were evaluated by means of energy dynamic simulations and then sorted according to a multi-criteria model. The application allowed to identify the best solutions aiming to maximize internal comfort and reduce operational energy and environmental costs of the building under investigation.

2 - Multicriteria evaluation and agent-based model for simulating housing mobility propensity of residents
Caterina Caprioli, Marta Bottero, Elena De Angelis, Marcus Foth, Peta Mitchell, Markus Rittenbruch, Marco Santangelo, Tan Yigitcanlar

The mixed-methods approach is considered as the "third paradigm" for social research, as it offers a powerful choice to integrate systematically quantitative and qualitative data. The present work explores the potentialities of combining agent-based model (ABM) and multicriteria decision analysis (MCDA) for supporting the definition of coherent policies in the context of urban transformations. The research analyses the gentrification dynamics that would occur after the transformation project of an actual golf park in the Kelvin Grove district (Brisbane, Australia) into a new urban park. On the one hand, ABM simulates on a medium-term the residents housing mobility through an individual decision-making process. The mobility likelihood of residents is based on various endogenous (i.e. household socio-economic characteristics) and exogenous (i.e. market variation) factors. Both house and household's characteristics derive from GIS empirical data. On the other hand, MCDA supports the identification of the relative importance of these factors using a panel of local experts and stakeholders. In particular, an analytic hierarchy structure and the Saaty's pairwise comparison are used to obtain the set of weights to be integrated into the mobility likelihood function. The different opinions of experts and stakeholders are tested to assess the parameters influences on the simulated outcomes and the model results are used to verify hypotheses and alternative policy scenarios.

3 - Dynamic SWOT Analysis as Supporting Tool for the Solution of Complex Problems in a Socio-Ecological System.
Vanessa Assumma, Marta Bottero, Elena De Angelis, Alessio Ishizaka, Ana Jacinta Soares

The contribution deals with the development of a Dynamic SWOT as an analysis tool to support the assessment of complex problems with interdependencies in the context of territorial plans and projects. Starting from a real world problem related to the landscape of the Champagne-Ardenne (France), the study demonstrates the D-SWOT functioning, by analyzing specific dimensions as meaningful for the resilience assessment and planning, i.e. Society, Technology, Environment, Economy, Policy, Landscape, and Ecology and investigates the relationships between the detected driving forces in terms of synergies and conflicts. The application of the D-SWOT has provided useful insights: on one hand, it supported the definition of a set of indicators to sort the resilience performance of the case study through the Group Analytic Network Process Sorting II method (GANPSort II); on the other hand, it contributed to the knowledge of ecological features as well as in the interpretation of the evolution scenarios through a mathematical model of network type. The paper discusses the findings of the D-SWOT matched with the results obtained by the GANPSort II and the network mathematical model and provides strategic recommendations and guidelines to increase the resilience of the investigated system.

■ WA-33

Wednesday, 8:30-10:00 - Virtual Room 33

Financial models

Stream: New challenges for financial modelling
Invited session
Chair: *Francesco Cesarone*

1 - Maximum risk diversification for portfolio selection
Francesco Cesarone, Rosella Giacometti, Fabio Tardella

We consider a new measure of diversification for a portfolio of risky assets and we address the problem of finding portfolios with maximum diversification, possibly with the addition of return constraints. The diversification measure is based on a convexity gap between the risk of a convex combination of assets and the convex combination of their risks. We first provide some theoretical results on this diversification measure and we establish connections with the Herfindahl index for risk. Then we formulate the portfolio diversification model for several risk measures. Finally, we provide some preliminary computational results.

2 - Power index-based assessment of risk in a portfolio of securities
Arsen Palestini

Following a recent paper by Shalit (Annals of Finance, 2020), we aim to extend the evaluation of risk in a portfolio of securities by considering the single assets as the players of a cooperative game of risk. Shapley and Banzhaf indices can both be employed in a setup of minimization of risk. Some additional cases are taken into account to deduce some general properties of power indices in the standard Markowitz framework.

3 - Optimal pair-trade execution with generalized cross-impact
Makoto Shimoshimizu, Masamitsu Ohnishi

We examine a discrete-time optimal pair-trade execution problem with generalized cross-impact. This research is an extension of Fukasawa, Ohnishi, and Shimoshimizu (2020), which considers the price impact of aggregate random orders posed by small traders with a Markovian dependence. We focus on how a risk-averse large trader optimally executes two correlated assets to maximize his/her expected utility from the terminal wealth over a finite horizon. A Markov decision process modeling constitutes the basis for the formulation of the optimal pair-trade execution problem. Then, under some regularity conditions, the backward induction method of dynamic programming enables us to derive the optimal pair-trade execution strategy and its associated optimal value function. The trading orders of each risky asset posed by small traders do affect the optimal execution volume of both risky assets. Moreover, numerical results with simulation experiments show that the cross-impact affects the optimal execution strategy and a round-trip trade exists for the large trader to utilize a 'statistical' arbitrage and to increase his/her expected utility under our model setting of cross-impact.

4 - Hawkes Carma(p,q) Models In Ruin Theory
Edit Rroji

In this paper we propose a new risk model for the dynamics of the capital in an insurance company. The insurance claims are modeled through an Hawkes process with random jump size where the intensity follows a CARMA(p,q) model with a self-exciting effect due to the presence of the counting process as a driving noise. Recent empirical studies have showed that the autocorrelation function of the number of claims has a decreasing trend but it is not strictly monotonic. A standard Hawkes model with exponential kernel for insurance claims developed in Swishchuk et al. (2021) is able to reproduce a exponential monotonic decreasing behaviour of the autocorrelation function. Our model, that can be seen as a generalization of the Hawkes process with exponential kernel, is able to generate a more flexible shape for the autocorrelation function and obtain a more realistic dependence structure observed in the number of claims

■ WA-34

Wednesday, 8:30-10:00 - Virtual Room 34

Integrated problem settings II

Stream: Combinatorial Optimization
Invited session
Chair: *Stefan Voss*
Chair: *Lin Xie*
Chair: *Natalia Kliewer*

1 - Potentials and Challenges for Integration of Electric Bus Fleets and PV-Systems
Paolo Graniero, David Rößler, Carolin Ulbrich, Natalia Kliewer

Bus transport systems are a backbone element for public transport in many urban and suburban areas. In an effort to reduce air pollution, bus operators around the world are implementing or are planning to implement electric buses (EB) into their fleets. This trend poses various challenges in terms of bus scheduling and power supply due to recharging process. If uncontrolled, the charging of a bus fleet can lead to disturbances to the local grid. This additional load can be supported with PV power generation. Stability problems can still arise due to the fluctuating behavior of both loads, positive (PV) and negative (charging). Since their successful integration depends on the coordination between them, PT operators using EB and leveraging PV power generation must considering these uncertainties.

A large body of literature exists on the optimal scheduling of electric buses, charging scheduling for electric buses, and the analysis of the grid impact of EV mass adoption. However, the importance of EB for the power grid with a special focus on renewable energies is underrepresented.

In our study, we present a state of research concerning the integrated consideration of EB, PV, and power system control putting special focus on the amount of uncertainty in both energy consumption of EB and PV-yield. Based on empirical data, we quantify the amount of fluctuations and uncertainties and explore the potential for better balancing of energy consumption and power supply.

2 - A Vehicle Routing Problem for Electric Vehicle Charging and Maintenance Scheduling
David Rößler, Nina Schwarm, Natalia Kliewer

Globally, an ever-growing number of car-sharing services and users can be observed. At the same time, such services integrate an increasing share of electric vehicles into their fleets. Both trends together may lead to reduced air pollution and decreased occupation of public space by the urban motorized individual transportation, if users give up self-owned private cars with internal combustion engines. As a prerequisite for consumers to make this transition, car-sharing services must offer a high service-level regarding vehicle availability and cleanliness. However, especially for operators of free-floating services, vehicle accessibility for tasks such as clean-up and charging is uncertain. Thus, performing these tasks can be costly and inefficient. Specialized service providers aggregate the demand for maintenance activities and perform them more cost-efficiently by combining tasks of multiple operators in tours, while adhering to a plethora of constraints. This gives rise to a dynamic planning problem with numerous sources of uncertainty, requiring an online solution approach. In this presentation, focusing on this interesting aspect of modern urban mobility, we propose a model for the underlying combinatorial problem. Moreover, we outline a dynamic Multiple Ant Colony (MAC) algorithm for the resulting Rich Vehicle Routing Problem. Lastly, the approach is evaluated using extended Solomon instances and real-world data from Berlin, kindly made available by Surve Mobility.

3 - A review of integrated optimization methods for vehicle scheduling, crew scheduling and crew rostering
Lena Wolbeck, Natalia Kliewer, Lucas Mertens, David Rößler, Lin Xie

The process of public transport planning consists of various decision problems. From a provider's perspective, vehicle scheduling, crew scheduling and crew rostering are challenging important planning steps at regular intervals. The planning has a major impact on operations, costs and the service quality for passengers. Whereas traditionally, the public transport planning is executed sequentially, a growing body of literature recognizes the shift to integrated solution methods. A vehicle schedule and crew roster can be improved using integrated methods, that solve several decision problems simultaneously due to the higher degrees of freedom in planning. We review solution methods for integrated optimization based on operations research techniques for the three problems mentioned. Furthermore, we extend the overview by a selected number of related methods from other industries. The overview provides a literature analysis according to various aspects. For example, we examine the optimization model, method and data used for computational experiments and classify them in terms of practical applicability. Overall, we present the state of the art and derive directions for future research strands that are close to real-world requirements. For example, a greater focus on the consideration of objectives besides cost minimization in integrated optimization methods could generate schedules that are more robust and roster that are fairer.

4 - Revisiting the Richness of Integrated Vehicle and Crew Scheduling
Liping Ge, Natalia Kliewer, Abtin Nourmohammadzadeh, Stefan Voss, Lin Xie

The last decade has seen a considerable move forward regarding integrated vehicle and crew scheduling in various realms (airline industry, public transport). With the continuous improvement of information and communication technology as well as general solvers it has become possible to formulate more and more rich versions of these problems. In public transport, issues like rostering, delay propagation or days-off patterns have become part of these integrated problems. In this paper we aim to revisit an earlier formulation incorporating days-off patterns and investigate whether solvability with standard solvers has now become possible and to which extent the incorporation of other aspects can make the problem setting more rich and still keep the possible solvability in mind. This includes especially issues like delay propagation where in public transport delay propagation usually refers to secondary delays following a (primary) disturbance. Numerical results are provided to underline the envisaged advances.

■ WA-35

Wednesday, 8:30-10:00 - Virtual Room 35

Initiatives in OR Education 1

Stream: OR Education Initiatives
Invited session
Chair: *Kseniia Ilchenko*
Chair: *Olga Nazarenko*

1 - Market Size Estimation of Higher Education Industry in Turkey
Ayşe Cilacı Tombuş, Abbas Dündar, Önder Tombuş

Higher education industry has been a big market in Turkey with the increasing number of private universities and more than 141 K enrolled students in 2020. On the other hand, there is no detailed study on the economic market size of the higher education industry. In this study, we tried to make an estimation on the economic market size of higher education industry in Turkey. The study concentrates on the undergraduate education including two year vocational schools and 4-6 year licence education which are subject to Central Placement Exam. The data are obtained from the public resources such as Council of Higher Education (YÖK) and university web pages. In the study, the data collection methods and assumptions used in the analysis have been described. Economic market size estimation has been presented and demographic effects; programs' value and the share on the market have been examined. In the final section, validity of the estimates have been discussed.

2 - The 7Es Instructional Model and its Longitudinal Impact on the Mathematics Achievement of Tertiary Students
Milagros Baldemor

This study aimed to determine the effectiveness of utilizing the 7Es Instructional Model on the Mathematics achievement in Calculus of tertiary students of the Don Mariano Marcos Memorial State University, Philippines in comparison with the traditional teaching method. The study sample consisted of sixty students who were divided into two groups: the experimental group of thirty students, who studied Calculus by using the 7Es Instructional Model - Elicit, Engage, Explore, Explain, Elaborate, Evaluate and Extend; and the control group of thirty students, who studied the same concepts using the traditional method. ANCOVA results of the students' scores in the mathematics achievement tests indicated that the 7Es Instructional Model is more effective than the traditional teaching method. Furthermore, the paired-sample t-test findings revealed that the model had a significant positive longitudinal effect on the retention among the students.

3 - Affect of Covid-19 Pandemic on the Mobility of University Applicants in Turkey
Önder Tombuş, Abbas Dündar, Ayşe Cilacı Tombuş

University education in Turkey is regulated by Council of Higher Education (YÖK) and applicants are placed according to a Central Selection and Placement Exam. More than 2 million candidates applied for the central exam and more than 600000 students have been placed to different universities in 81 cities. In this study we have examined how Covid-19 pandemic has affected the city preferences of students who have been placed. We examined the statistical data of more than 10000 different programs. The home city of the students who have been placed was analyzed and it was compared with the mobility of students in previous years to estimate the affect of Covid-19 Pandemic on the mobility of year 2020 applicants.

4 - Addressing the 'analytical competence gap' in Community OR : How can OR practitioners have 'meaningful engagement' during and beyond the project scope?
Maimanah Idris, Ine Steenmans

Experienced Community OR practitioners stress the need for a OR research process that combines analytical methods into a methodology capable of meeting the project aims. A critical component of these aims are the needs of stakeholders other than those of the Operational Researcher. OR experts have stated that even the most intuitive &widely utilised analysis approach has little value if it doesn't sufficiently respond to issues meaningful to stakeholders. The implications for both novice &experienced OR researchers is a required competence in adapting methodologies to include the needs of stakeholders unfamiliar with OR &its methodologies. There is a growing research area that calls for the requisite 'analytical competence' for developing inclusive &empowering OR methodologies. However, there is a related set of observations that there is an analytical competence 'gap' between the intended &actual stakeholder experiences when systems mapping is used to add value in OR projects. We responds to a related knowledge gap & some of the practical ways by which this gap can be addressed. First, we summarise lessons from the literature. Second, we analyse OR research process experiences, systems methodology information asymmetry, &challenges in addressing inclusive analytic competence. Finally, we reflect on the intentional use of reflexive methodological studies to bridge strengths of early career OR researchers with supervising OR practitioners &valued stakeholders.

■ WA-36

Wednesday, 8:30-10:00 - Virtual Room 36

Game Theory, Solutions and Structures III

Stream: Game Theory, Solutions and Structures
Invited session
Chair: *Michel Grabisch*

1 - The Priority Value for Cooperative Games with a Priority Structure
Philippe Solal, Sylvain Béal, Sylvain Ferrières

We study cooperative games with a priority structure modeled by a poset on the agent set. We introduce the Priority value, which splits the Harsanyi dividend of each coalition among the set of its priority agents, i.e. the members of the coalition over which no other coalition member has priority. This allocation shares many desirable properties with the classical Shapley value: it is efficient, additive and satisfies the null agent axiom, which assigns a null payoff to any agent with null contributions to coalitions. We provide two axiomatic characterizations of the Priority value which invoke both classical axioms and new axioms describing various effects that the priority structure can impose on the payoff allocation. Applications to queueing and bankruptcy problems are discussed.

2 - Ewens Distribution, Potential, and the IDD Value for Games with Externalities
Frank Huettner, André Casajus

Cooperative games with externalities (TUX games) emerge as a more realistic and more general approach to cooperative games with transferable utility (TU games). Studying TU games with varying player sets has been very fruitful, in particular to understand the nature of the Shapley value. The IDD solution is an extension of the Shapley value to TUX games. We give a notion of subgames (restriction), a potential function, and new characterizations for the IDD solution. The connection to random partitions, specifically to the central Ewens distribution is highlighted.

3 - Allocation Rules for Multi-choice Games with a Permission Tree Structure
David Lowing

We consider multi-choice cooperative games with a permission tree structure. Multi-choice games are a generalization of cooperative transferable utility games in which each player has several activity levels. In addition, a permission tree structure models a situation in which a player needs permission from another player to cooperate. In this framework, the influence of a permission structure on the possibility of cooperation may have several interpretations depending on the context. In this paper, we investigate several of these interpretations and introduce for each of them a new allocation rule that we axiomatically characterize.

4 - k-additive upper approximation of TU-games
Michel Grabisch, Agnieszka Rusinowska

We study the problem of an upper approximation of a TU-game by a k-additive game under the constraint that both games yield the same Shapley value. The best approximation is obtained by minimizing the sum of excesses with respect to the original game, which yields an LP problem. We show that for any game with at most 4 players all vertices of the polyhedron of feasible solutions are optimal, and we give an explicit formula of the value of the LP problem for a particular class of games.

■ WA-37
Wednesday, 8:30-10:00 - Virtual Room 37

Modelling the value of medicines, vaccines and social interventions to tackle infectious diseases 2

Stream: Ethics in OR
Invited session
Chair: *Alec Morton*

1 - Investigating a Subscription Payment Model for Antibiotic Purchasing
Euan Barlow, Alec Morton, Itamar Megiddo, Abigail Colson

Novel subscription payment schemes are one of the approaches being investigated to tackle the threat of antimicrobial resistance. One example is the scheme currently being piloted by the UK government separating overall payment of an antibiotic into a fixed lump-sum component and a component dependent on sales-volume. Intended to incentivise investment in development of new antibiotics, this scheme will enable the government to consider societal benefits when determining payments for antibiotic treatment. This payment scheme significantly increases the complexity of decision making for HTA bodies, ensuring that sufficient incentive can be provided to the pharmaceutical industry to encourage innovation, whilst managing the responsible use of the antibiotics developed, and maximising the benefits to society from investment in this innovation. We present a mathematical model of subscription payment schemes to estimate the total returned welfare, explicitly featuring fixed and volume-based payment components. Decisions to allocate antibiotic treatment and subsequently measure treatment benefits are modelled with individual-based and societal-based valuations, respectively. Treatment of Gonorrhoea is used to illustrate application of the model, and the impact of different pricing decisions on the optimal returned welfare.

2 - Estimating the Impact of a Novel Gonorrhoea Therapy with Structured Expert Judgement
Abigail Colson, Davood Sabaei, Itamar Megiddo, Alec Morton

Current Health Technology Assessment (HTA) methods do not capture the full range of costs and benefits related to antimicrobials, as they focus on treatment costs and health benefits accrued by an individual patient and miss population-level costs associated with the spread of resistance and benefits associated with reduced transmission and reduced selection pressure on other treatment options. These values cannot be directly obtained from a clinical trial or estimated through traditional disease models. An alternative approach is to use structured expert judgement. We develop a protocol to elicit future resistance rates in the context of a hypothetical new antimicrobial to treat gonorrhoea infections in the United Kingdom. Using Cooke's Classical Model of structured expert judgement also allows us to assess the statistical accuracy and informativeness of the experts to validate their assessments and combine them into a performance-based aggregated assessment. The outputs from the structured expert judgement process can be used to estimate additional costs and benefits of a new antimicrobial, making them useful for a HTA evaluation. Qualitative information on the rationales for the experts' assessments and their understanding of the causes of changing resistance patterns more generally can also help disease modellers better understand the factors that contribute to the emergence and spread of resistance, improving future modelling capacity in this area.

■ WA-38
Wednesday, 8:30-10:00 - Virtual Room 38

Optimization Models in Humanitarian Logistics

Stream: Humanitarian Operations
Invited session
Chair: *Sibel Salman*

1 - Large Scale Urban Evacuation Planning and Management: A Zone-Based Approach
Vedat Bayram, Hande Yaman

We develop models and solution methodologies that jointly consider supply and demand management strategies for an efficient evacuation planning/management. We propose a Cell Transmission Model based mixed integer programming formulation that accounts for evacuate or shelter-in-place, staging and dynamic resource allocation decisions simultaneously. Then, we present exact solution methodologies based on Benders decomposition to solve the problem efficiently for realistic size instances. We further transform Benders subproblem into a network flow based formulation on a time-expanded network and explore other strategies such as obtaining strong and initial optimality cuts and generating valid inequalities for the master problem to enhance the performance of proposed algorithm. We conduct experiments to demonstrate the efficiency of the proposed algorithms and derive managerial insights.

2 - Multi-period Mobile Facility Location for Relief Aid Provision to En Route Refugees
Baturhan Bayraktar, Dilek Gunnec, Sibel Salman, Eda Yücel

To aid humanitarian organizations in planning their relief aid operations targeted at en route refugee groups who are on their walk to cross borders, we model a multi-period facility location problem in which both facilities and demand are mobile on a network. Following predetermined paths, refugee groups enter and exit the network in different periods. Refugee groups traverse from one node to the next between consecutive periods. A refugee group on the network must be served at least once in a prefixed number of consecutive periods for service continuum. In each period, the refugee groups at a node are served if a mobile facility is at the same node. The problem locates each mobile facility to a node in each period and minimizes the total setup and travel costs of the facilities. We call this problem the multi-period mobile facility location problem with mobile demand. We prove its NP-hardness and formulate a mixed integer linear programming (MILP) model. To solve large-size instances, we develop an adaptive large neighborhood search algorithm (ALNS). We test the performance of the MILP and ALNS by extracting data from the 2018 Honduras Migration Crisis. For instances solved to optimality by the MILP model, ALNS determines the optimal solutions faster and provides better solutions for the remaining instances. By analyzing the sensitivity to various parameters, we provide insights to decision-makers.

3 - Logistics planning of cash transfer to Syrian refugees in Turkey
Sibel Salman, Ramez Kian, Gunes Erdogan, Sander De Leeuw, Ehsan Sabet, Bahar Yetis Kara, Muhittin Hakan Demir

We address a humanitarian logistics problem connected with the Syrian refugee crisis. The ongoing conflict in Syria has caused the displacement of millions of people. Cash-based interventions play an important role in aiding people in the post-crisis period to enhance their well-being in the medium and long term. We present a study on how to design a network of administrative facilities to support the roll-out of cash-based interventions. The resulting multi-level network consists of a central registration facility, local temporary facilities, mobile facilities, and vehicles for door-to-door visits. The goal is to reach the maximum number of eligible beneficiaries within a specified period while minimizing logistics costs, subject to a limit on total security risk exposure. A mixed integer programming model is formulated to optimize the inter-related facility location and routing decisions under multiple objectives. We develop a hierarchical multi-objective matheuristic algorithm to obtain efficient solutions. An application of the model and the solution algorithm to real data from a region in the southeast of Turkey is presented, with associated managerial insights.

4 - A location-allocation model for humanitarian relief operations during pandemic outbreak
Yashoda Devi, Sabyasachi Patra

Pandemics have always been a curse to human civilisation, causing great suffering and human lives. The recent outbreak of the COVID-19 pandemic is one such example, that has claimed millions of lives globally. Due to the COVID-19, the existing healthcare system is being overburdened by the increased demand of vulnerable and contaminated people. To prevent the pandemic from spreading, it is critical to locate and isolate infected individuals. Therefore, in the present study, we develop a mixed-integer programming model for the location of the temporary testing laboratories. Specifically, the objective is to locate the temporary testing laboratories to minimise their maximum distance from the customer zones at minimum cost. This is to ensure equity of services to all geographical location. The real-life applicability of the model is demonstrated using the case of Maharashtra, India.

■ WA-39

Wednesday, 8:30-10:00 - Virtual Room 39

Game Theory and Operations Management 4

Stream: Game Theory and Operations Management
Invited session
Chair: *Shoshana Anily*

1 - Equity Crowdfunding
Ella Segev, Arieh Gavious, Hana Tzur

Equity crowdfunding is a method of financing an initiative whereby an entrepreneur sells shares of her firm to the crowd. Equity crowdfunding is becoming increasingly popular and its potential economic impact is significant. We develop a common value crowdfunding game theoretic model, where the entrepreneur sells a percentage of the firm and then shares the future value of it with the crowd. Potential investors' arrival process is stochastic. In each period, a potential investor is born with some probability, receives a signal on the future value of the firm, observes the current state of investment and then decides whether to invest in the firm or not. By offering a different share in the firm the entrepreneur leads the crowd to different equilibria. We characterize these equilibria, analyze when the investors' behavior exhibits herd behavior (i.e., investors ignore their own signal and follow the behavior of previous investors) and find the entrepreneur's best decision given the firm's probability of success and other characteristics.

2 - Sensitivity analysis for the hospitals-residents with consistent couples matching model
Nitsan Perach, Shoshana Anily

The hospitals-residents with consistent couples (HRCC) model is a generalization of the original Gale-Shapley hospitals-residents (HR) stable matching model, in which the residents set consists of singles and couples. The joint preference-list of any couple over pairs of hospitals is consistent with the preference-list of each of its partners. A feasible stable assignment has the property that the residents of each couple are assigned to a pair of hospitals in their joint preference-list or they are both unassigned. In this paper we study the implications on the existence and on the form of a feasible stable assignment by the following changes of a given HRCC instance: (i) forming or breaking couples; (ii) new arrivals or departures of residents; and (iii) increments or reductions of the number of open positions in hospitals. In particular, we propose an algorithm that generates a feasible stable assignment, if such one exists, for the case that new residents arrive, by starting from a feasible stable assignment over the set of residents before the new arrivals. Similarly, if some residents depart, we make use of a feasible stable assignment that existed before the departure in order to phrase an alternative stopping condition while searching for a feasible stable assignment after the departures.

3 - Total balancedness of a parallel job-splitting scheduling game
Shoshana Anily, Tzvi Alon

There is a rich stream of research on cooperative games in scheduling where the focus is on sequencing games, but little is known about cooperative games of Parallel Machine Scheduling (PMS), which are widely used in distributed computing systems. To the best of our knowledge, this paper is the first that is devoted to a cooperative game of a PMS problem. We consider a set of players, where (i) each player is associated with a set of jobs and a set of machines; (ii) each job is characterized by its processing requirement; and (iii) each machine is characterized by its speed. The machines are uniform in the sense that each can process any job. The jobs can be split and processed simultaneously on different machines. The objective is minimizing the sum of the completion times of the jobs. We prove that the associated cooperative game is totally balanced by presenting a symmetric convex set of core cost allocations.

4 - Partial Vertical Ownership and Information Exchange in a Supply Chain
Noam Shamir, Tal Avinadav

Partial vertical ownership describes a situation in which a firm holds financial shares either in its supplier (referred to as partial backward integration) or in its customer (partial forward integration). We study the effect of such financial interconnectedness on two operational decisions: capacity investment and information exchange. In our model, a retailer, who has superior information about the future market demand, possesses some level of passive financial holdings in the supplier. Although this passive financial investment does not enable the retailer to directly influence the supplier's operational decisions, it does affect the market equilibrium. Specifically, financial interconnectedness between the firms can result in the retailer financing the entire capacity in the market. In addition, we characterize the conditions that ensure information between the retailer and the supplier can be exchanged by "cheap-talk" communication. When "cheap talk" is not possible, we study the separating equilibrium that is achieved by the retailer's commitment to order in advance. Interestingly, this advance order can be either decreasing or increasing with respect to the level of the financial holdings.

■ WA-40

Wednesday, 8:30-10:00 - Virtual Room 40

Miscellaneous scheduling problems

Stream: Scheduling and Project Management
Invited session
Chair: *Daniel Lifshitz*

1 - Reinforcement Learning for Scheduling
Tuba Ulusoy, Gurkan Ozturk

Scheduling is a combinatorial optimization problem in which jobs are assigned to machines considering one or multiple scheduling criteria, such as minimizing total tardiness, minimizing the number of late jobs, and maximizing system/resource utilization. It is known that scheduling directly affects the productivity of the production systems, therefore, solving scheduling problems in reasonable computational times and obtaining optimal or near-optimal solutions have gained great interest both in research and practical applications. Various methods and techniques have been needed to be developed and applied to solve scheduling problems that also meet the different requirements of different types of production systems. Since Reinforcement Learning (RL) which is one of the machine learning algorithms, provides promising solutions to even complex and large scheduling problems, in this study, a comprehensive literature review about RL approaches for scheduling problems is presented to shed light on current studies and investigate possible research directions.

2 - Simultaneous Stochastic Project Scheduling and Resource Allocation Under Uniform and Triangular Distributions for Activity Resource Requirements
Ekin Tanir, Kadir Ertogral

A project schedule serves the purpose of controlling costs and optimizing resources. Along with project activity scheduling, resource allocation is also a key component for project management. Within the scope of both problems in the literature, there are numerous examples for deterministic models considering the required time or effort. However, in real life applications, the required efforts for the activities are observed mostly as stochastic parameters. In our study, stochastic optimization models using random activity resource requirements are suggested. Our models are extensions of Felberbauer et al. (2018) where the main objective is to minimize the expected cost of external resources needed. We extend their model in two aspects; First, instead of a general distribution used in Felberbaurer et al. (2018), we assume both uniform and triangular distributions for the activity resource requirements because these distributions are the most suitable or encountered ones in real life applications. Besides, this assumption allowed us to formulate the expected cost in the objective of models in close forms. Secondly, we relaxed their assumption that the project activities cannot continue for more than one period. We suggest a more flexible model in this regard and show the benefits of this flexibility.

3 - Inbetween PMBOK, PMOs, and Textbooks
Pini Davidov, Nadine Ayoubi

Academic textbooks marks main points of interest across time, however, it doesn't always keep up with the on-the-ground practical needs of different industries. This article discusses the Project management body of knowledge 6 (PMBOK) Knowledge areas (KA), their usage among active PMO's, their coverage in academic textbooks, and the relation between them. A textbook analysis across the last 3 decades was performed, 12 samples per decade. The books were then classified by topics and coverage ratio (pages dedicated to each topic). A survey was conducted among active PMO's (n=117) from various fields, such as digital, IT, construction and other industries. Participants were asked to rate their level of knowledge and usage of PMBOK KA. Findings show Quality and Scope are prominent leads across textbook generations, and increased coverage of Risk-Management (p=0.002) and a decreased coverage of Stakeholders (p=0.035) over the years. Also, there was an alignment in between generations among topic coverage. PMO's reported Integration, Scope, and Time as the most familiar to them, Time is most used, and Cost as a KA that they wish to know more about. Seniority correlates to a lesser interest in learning more about KA and vice versa. These results raise the need to increase the connection between academic training and practical users (creating a cost focus course and emphasizing cost in the curriculum, creating and reaching young PMO's continuing education program course).

4 - Genetic Algorithms for the Resource Coordinating Scheduling Problem
Daniel Lifshitz

Coordinating the work of renewable resources (RRs), such as robots that operate simultaneously, is crucial in the industry 4.0 environment that enables the smart factory. This paper deals with a scheduling problem in which an operation may share different RRs simultaneously, consider a set of operations including precedent relationships and perform using alternative modes that define the subset of the resources needed. A previous genetic algorithm (GA1) that is used to solve this problem suffers from a high rate of infeasible offspring genotypes due to the algorithm encoding. This paper presents new GAs (GA2_M and GA2_S) that produce only feasible genotype offspring. While in GA1, the genotype consists of all the solution 0-1 variables, in GA2, a genotype that stores only enough information to generate a phenotype is used. Our main objective is to develop a heuristic with a shorter runtime than that of GA1 with an ideal deviation from the optimal solution. The runtime of GA2_M and GA2_S was faster for both large and small problem instances when compared to the runtime of GA1. Moreover, the makespan of GA2_M was better than that of GA1 regarding the larger instances. In 75.4% of the instances, GA2_M and GA2_S have the same makespan, but in 16.4% GA_M surpasses GA_S, and only in 8.2% does GA_S outperforms GA2_M.

■ WA-41

Wednesday, 8:30-10:00 - Virtual Room 41

Warehousing and port terminal planning

Stream: Production and logistics and revenue management (contributed)
Contributed session
Chair: *Consuelo Parreño-Torres*

1 - Human factors in warehouse planning: review and insights from practice
Thomas De Lombaert, Kris Braekers, René de Koster, Katrien Ramaekers

Warehouses play a vital role in a company's supply chain and contribute to the failure or success of modern-day companies. Although many activities are performed within a warehouse environment, it has been demonstrated that order picking (OP) is by far the costliest. A driving force behind these costs is the degree of congruence between the OP system and OP planning. This particular research focusses on the interface between human-involved OP systems and tactical and operational OP planning models, with the idea of integrating insights from the human factors discipline (or ergonomics) within operations research models for typical planning problems like batching, routing and job assignment.

First, a systematic review of the relevant literature is discussed. Rather than focussing on which human factors are integrated in OP planning problems, the focus is on the employed methodology to carry out this integration. Second, this review is complemented with practice-based insights, gathered via semi-structured interviews with both order pickers and their managers in a wide range of industries. The ensemble identifies practitioners' needs and demonstrates the prevalent disconnection between theory and practice. These findings are finally translated into future research opportunities for integrating human factors in OP planning models.

2 - Scattered Storage Strategy with SKU-specific Bulky Locations of E-commerce Fulfilment Warehouses
Mengya Liu, Kim Leng Poh

In the e-commerce era, fast order fulfillment becomes a critical competitive advantage for the online retailing industry. When the traditional warehouse storage strategies are overwhelmed by the demand surge brought by the e-commerce boom, the scattered storage strategy provides another assignment solution to facilitate the fulfillment of a vast number of heterogeneous time-critical orders. Scattered storage strategy explodes the incoming bulk of the same SKU into several small stocking loads and scatters them to different storage shelves. By increasing the scatteredness, the probability of having nearby location(s) containing the wanted item increases, and the traveling distance incurred during the order fulfillment process potentially decreases. This paper develops a novel scattered storage assignment approach that is tailored to suit B2C e-commerce fulfillment warehouses, and it is formulated as a MIP problem. Firstly, we present a new measure of scatteredness and form the objective function based on that. Then, SKU-specific bulky location is introduced as a constraint to tackle the issues of varying quantities per SKU from order to order. A two-stage heuristics algorithm is developed to solve the problem and is benchmarked against a mathematical optimization solver. The results from different test scenarios show the effectiveness and efficiency of the proposed algorithm. Finally, a simulation experiment is conducted to validate the appropriateness of the proposed model.

3 - Tree search methods for solving the unit-load pre-marshalling problem in block stacking storage systems
Jakob Pfrommer, Anne Meyer, Kevin Tierney

A block stacking storage system is a type of warehouse system that is highly adaptable and has low investment costs. While block stacking storage systems with multi-deep lanes can achieve high storage densities, the accessibility can be problematic. Unit-loads can only be accessed one after the other starting from the outermost items. The unit-load pre-marshalling problem seeks to utilize off-peak hours to rearrange a block stacking storage to prepare for upcoming orders. The goal is to find a minimum number of unit-load moves needed to sequence a storage bay in ascending order based on the duration of stay of each unit-load. In this talk, we present several lower bound heuristics for the number of item moves. First, we show that for storage bays with one access direction, it is possible to adapt existing lower bound heuristics from the container pre-marshalling problem. However, more complex scenarios with multiple access directions require alternative approaches. Therefore, we develop a novel lower bound heuristic based on a network flow model that is applicable in all scenarios. Based on the proposed lower bound heuristics, we implement tree search methods to solve the unit-load pre-marshalling problem. We then analyze the performance of the presented solutions in computational experiments for randomly generated problem instances. Finally, we point out that the presented approach is also useful to tackle further decision problems in block stacking storage systems.

4 - A constraint programming approach for the premarshalling problem
Celia Jiménez-Piqueras, Consuelo Parreño-Torres, Rubén Ruiz, Ramon Alvarez-Valdes

Port terminals are essential nodes in container transportation of goods. In the last decades, the amount of containers transported has seen an enormous growth and so has the difficulty of operating the terminals efficiently. Thus various optimization problems have arisen in this context with the objective of minimizing the inefficiencies that exist in different port areas. In particular, the "premarshalling" problem is defined in the port yard, an area where containers are temporarily stored. Containers are placed in stacks, so they follow a Last In, First Out structure. Hence, when a container has to be retrieved, all the containers above it have to be reshuffled first, which is very time consuming. The aim of the premarshalling problem is to find the minimum number of crane moves necessary for reordering a bay (set of containers placed in adjacent stacks) in a way that no container is above another with an earlier retrieval time. This reorganization is performed when the cranes are not being used to retrieve containers or to place new ones, and it allows for faster loading and unloading of vessels. In this work, a series of four constraint programming models for solving the premarshalling problem is presented.

■ WA-42

Wednesday, 8:30-10:00 - Virtual Room 42

New Problems and Methods in Epidemiology

Stream: Stochastic Dynamic Programming
Invited session
Chair: *Javier Cabrera*
Chair: *Michael Katehakis*

1 - Forecasting daily confirmed cases and deaths of COVID-19 using a novel dynamic pattern extraction and matching algorithm
Debopriya Ghosh, Dhammika Amaratunga, Javier Cabrera, Michael Katehakis, Jin Wang, Wenting Wang

Accurate forecasts of daily confirmed cases and deaths can help estimate the global impact of the novel coronavirus (COVID-19) and design containment measures and mitigation policies. In order to be able to forecast accurately, it requires ample historical data. Moreover, forecasts are influenced by the reliability of the data and exogenous factors. In this work, we develop a novel technique for forecasting using limited data. Unlike, in case of seasonal flu outbreaks where we observe a periodic pattern repeated each year, in COVID-19 we do not have any distant historical data. Our novel forecasting method addresses this issue by combining multiple shorter time-series. The data was preprocessed by smoothing and variance stabilizing transformations. After preprocessing we applied dynamic change point analysis to segment the time-series into sub-series that represent a distinct structural pattern. Each segment is regularized by a linear transformation that makes the patterns location and scale free. We also classify the patterns into peaks and valleys. The forecasting algorithm uses a pattern matching approach to estimate the future trend by extrapolating the extracted scale-invariant patterns. We incorporated dynamic weights to our algorithm. Overall, our method demonstrated superior performance compared to deep-learning and auto-regressive models. Based on both RMSE and MAE, our proposed method obtained reliable forecasts across a wide range of scenarios.

2 - The impact of socio-economic factors on the spread of COVID-19 cases and deaths
Wenting Wang, Dhammika Amaratunga, Javier Cabrera, Debopriya Ghosh, Michael Katehakis, Jin Wang

In this study, we investigated the possible effect of several local socio-economic factors on the case count and time course of confirmed Covid-19 cases and deaths across all New Jersey counties. Factors considered included population, percentage of elders in the population, percentage of low-income households, access to food and health facilities and distance to New York. In order to acquire socio-economic data related to access to food and health we searched the data from the Yelp Fusion API for all NJ counties. The cumulative daily cases and deaths as a function of time were compared using a dissimilarity based on areas between the curves using Simpson's rule, followed by multidimensional scaling. We found that the counties could be clustered into three groups based on (a) the case totals, (b) the total number of deaths, (c) the time course of the cases and (d) the time course of the deaths. The four sets of clusters were very similar to one another and could all be largely explained by the county population, the percentage of low-income population, the distance of the county from New York and socio-economic factors. As for food and health factors, the access to food and health significantly influenced the total number of cases and deaths as well as the epidemic's evolution. Overall, our study found that the evolution of the epidemic was influenced by certain socio-economic factors, which could be helpful for the formulation of public health policies.

3 - Adaptive learning models and techniques for forecasting COVID-19 daily cases and deaths
Jin Wang, Dhammika Amaratunga, Javier Cabrera, Debopriya Ghosh, Michael Katehakis, Prateek Purwar, Wenting Wang, Arpit Yadav

Effective surveillance of disease evolution over space and time is crucial for designing intervention and mitigation strategies to deal with pandemics like COVID-19. In this work, we explore adaptive learning techniques to forecast confirmed COVID-19 daily cases and deaths for short-term and medium-term dependencies for the state of New Jersey.

In our study, we have obtained the daily confirmed cases data from the world meter website for the state of New Jersey. We describe how data irregularities necessitated the use of data prepossessing using variance stabilizing transformations. This was followed by smoothing splines, and deep learning techniques. We applied two deep learning models namely CNN and LSTM. In contrast to CNN, the LSTM networks use a pre-specified time window to accurately capture complex multivariate sequences. Further, we also compared Naïve and sequence-to-sequence modeling approaches. Our results indicated that LSTM has lower RMSE values when compared to CNN. The results also showed that a sequence-to-sequence approach is better suited for forecasting COVID-19 daily cases and deaths.

In conclusion, our analysis demonstrated that the LSTM model provided superior forecasting performance as well as the ability to capture the highly dynamic pattern of the evolving pandemic.

4 - A comparison of multiple forecasting methods for the daily cases and deaths of Covid-19.
Javier Cabrera, Dhammika Amaratunga, Debopriya Ghosh, Michael Katehakis, Prateek Purwar, Jin Wang, Wenting Wang, Arpit Yadav

Several methods have been proposed for forecasting the dynamics of the cases and deaths related to Covid-19 from the statistical/machine learning methodology. Such methods include pattern matching forecasting, Deep learning using RNN-LSTM and CNN. Also, there are other important methods for forecasting the annual flu epidemic such as the ARGO models and other long time-series forecasting models.

In this presentation we compare deep learning methods with time-series methods for forecasting NJ COVID-19 data. We will provide further insights about the applicability of these methods.

■ WA-43
Wednesday, 8:30-10:00 - Virtual Room 43

Ranking in sports

Stream: OR in Sports
Invited session
Chair: *Dmitry Dagaev*

1 - Japanese University Baseball ranking calculated by Elo Rating Method
Takashi Toriumi

Baseball is very popular in Japan. In particular, university baseball has the longest history. There are 26 university baseball leagues, and each league is independent, so there are few opportunities for universities belonging to different leagues to play each other. Therefore, calculating the rating of each university and making a cross-league ranking of university baseball will attract attention not only from baseball fans but also from university officials. The purpose of this study is to investigate the optimal ratings in Japanese university baseball leagues, covering a total of 15 leagues from the spring league of 2012 to the spring league of 2019. The leagues consisted of six teams playing two or more rounds. Elo rating was used to calculate the ratings. The value of k was calculated by considering not only wins and losses but also score differences. We examined the optimal values of the two levels of k according to the score difference and found that the highest maximum likelihood values were obtained in the case where the score difference of up to three was considered a close game. In this case, the probability that the team with the highest rating wins is 85.5%. For each university's initial rating, we examined the extent to which it inherited the final rating of the previous league. The likelihood was the same for all the leagues. This means that the difference of the initial value has little effect on the final rating of the league in this league format.

2 - Discovering the next Eddy Merckx
Dries Goossens, David Van Bulck, Arthur Vande Weghe

In various sports, large amounts of data are nowadays collected and analyzed to help scouts in identifying talented young athletes. In contrast, the literature on data-based scouting in road cycling is scarce if even existing. We aim to provide insight into the possibilities of the use of publicly available data to discover new talented Under-23 (U23) riders via statistical learning methods. At the same time, we try to find out the main determinants of success for U23 riders in their first years of professional cycling. We collect results for more than 25,000 road cycling races from 2007-2018 and consider more than 2,500 riders from over 80 countries. We use the data from 2007 to 2017 to train and validate our models, and use the data from 2018 to predict how well U23 riders will perform in their first three elite years. Our results reveal that past U23 race results appear to be important predictors of future cycling performance.

3 - Players' Average Marginal Contribution in Basketball and Generalized Shapley Value
Rodolfo Metulini, Giorgio Gnecco

The issue of how to measure players' importance in team sports is gaining more and more relevance - mainly because of the advent of new data and advanced technologies - in order to help professional coaches and staff with the final aim of winning the game. In this paper we evaluate each player's importance - for the first time in basketball - by computing his average marginal contribution (averaged along all the lineups in which that player was in) to the utility of an ordered subset of players, through a generalized version of the Shapley value. A peculiarity is that the value assumed by the generalized characteristic function of the generalized coalitional game is here represented by the probability a certain lineup has to win the game. This probability is estimated by applying a logistic regression model, where the response is represented by the game outcome and the so called four Dean's factors are used as explanatory features. The proposed approach is applied to play-by-play data covering fourteen full NBA seasons (from 2004/2005 to 2017/18) in order to obtain generalized Shapley values of single players. The evaluation of each player's generalized Shapley value compared with his income permits to find those players whose average marginal contribution is higher than expected.

4 - Monsters are not Real! Critique of Artificial Players in the Bradley-Terry Framework
Dmitry Dagaev

The Bradley-Terry model can be used to construct tournament competitors' ranking based on the pairwise comparisons. In a recent paper, Hankin(2020) proposed a generalization of the Bradley-Terry model that incorporates draws in a standard variant of the model allowing only wins and losses. An artificial player ('a Draw monster') was added into a two-sided non-strategic contest, so that each game could be interpreted as a three-sided non-strategic contest; a win of a Draw monster means that the initial two-sided contest ends up in a draw. I provide several critical arguments why modelling draws with an artificial player in the Bradley-Terry framework seems to be not a good idea.

■ WA-45

Wednesday, 8:30-10:00 - Virtual Room 45

Retail Inventory Management

Stream: Demand and Supply in Consumer Goods and Retail
Invited session
Chair: *Marcus Brandenburg*

1 - Using Internet-of-Things Data at the Point-of-Consumption for Demand Forecasting and Inventory Management: The Case of Professional Coffee Machines
Sandria Weisshuhn, Yale T. Herer, Kai Hoberg

Internet-of-Things-enabled systems that monitor inventories and sales are the next technological advancement in demand forecasting and replenishment. Unlike traditional systems that record purchases via cash registers or RFID technology at the point-of-sale, these novel systems can track product usage via smart, connected devices at the point-of-consumption, i.e., directly at the end user. This usage data promises to be a valuable basis for automated ordering and replenishment processes. We study such a system in the context of professional coffee machines and collaborate with a large manufacturer/retailer in the coffee industry. Our dataset contains information on more than 83 million drinks served since 2018 for nearly 6,500 customer-machine combinations. Complexities in this context pertain to unique usage patterns in different customer segments (such as office kitchens, gastronomy, and gas stations), different customer behavior in managing machine supplies, and the integration of multiple machine types into a common system. We approach these challenges by estimating segment-specific models for demand forecasting and customer-specific models for inventory management. In addition, we incorporate human and technology-based inventory record errors into our inventory models. Overall, we seek to develop tools for managing smart replenishment systems in practice. Our findings extend to consumer contexts and suggest important implications for both stationary and online retail.

2 - Influence of Returns on an Omni-channel Retailer's Inventory Policy
Joost Goedhart, René Haijema, Renzo Akkerman

As traditional and online shopping is becoming more integrated, retailers need to reconsider their inventory policies. The growth of online shopping has also resulted in increasing numbers of product returns. Handling these returns efficiently can have significant influence on the profitability of the retailer. One of the promising strategies is leveraging brick-and-mortar stores for the fulfilment of online orders and the handling of returned products. In practice, this also means that the inventory is rationed across the different shopping channels and returned products can be added to the store inventory. In this paper, we research the rationing and ordering decisions of a retailer while taking into account the return flows of the online channel. We formulate the model as a Markov Decision Problem (MDP) that maximises the expected profit. As the combination of rationing, ordering, and returns leads to high dimensionality of the problem, an MDP easily becomes intractable. Therefore, we develop a reinforcement learning (RL) algorithm. We compare the RL algorithm with the MDP, and derive managerial insights based on the results.

3 - Single Item Periodic Review Inventory Control with Sales Dependent Stochastic Return Flows
Esra Gokbayrak, Enis Kayis
Retailers have to deal with increasing levels of product returns as the shares of e-commerce sales soars. With this increase, it is no longer feasible to dispatch returned products to outlets or landfills, hence retailers must re-evaluate them both to maximize profit and to minimize their environmental impact. Our objective is to study a retailer's optimal inventory control policy under product returns to maximize expected profit which is the sales revenue minus the procurement, backorder, holding, and salvage costs incurred in a finite horizon. We model a period's returns to be stochastically dependent on the previous period's sales quantity. Using dynamic programming formulation, we solve for the optimal periodic review inventory policy. Through numerical studies, we show that incorporating sales-dependent returns could increase a retailer's expected profit by 23%. Ignoring this dependency in determining the optimal inventory policy results with increased order frequency and higher levels of backorders that would be eliminated otherwise.

4 - Competition between modern retail chains and unorganized retailers in emerging markets
Jiwen Ge, Brian Tomlin, Jan C. Fransoo
Emerging-markets feature the co-existence of large-scale supermarkets as organized retailers and high-density mom-and-pops as unorganized retailers. We model a multi-unit game where a CPG manufacturer sells a product to both retail formats which compete for consumers via retail pricing. We study the wholesale and retail pricing equilibrium.

■ WA-46

Wednesday, 8:30-10:00 - Virtual Room 46

Capacity Allocation and Revenue Management

Stream: Revenue Management and Pricing
Invited session
Chair: *Luce Brotcorne*
Chair: *Lama Moussawi-Haidar*

1 - A Two-Period Hotel Revenue Management Problem with Capacity Allocation and Cooperation with Third-Party Agencies
Nazli Karatas Aygun, Onder Bulut
A hotel revenue management problem is studied where overbooking, capacity rationing, and cooperation with third-party websites are simultaneously considered in a two-period optimization model. Capacity rationing is a strategy that enables to set demand acceptance rules based on customer segmentation and prioritization. In a Stackelberg game structure, hotel, as being the leader, decides on the price, overbooking and capacity rationing levels. Then, third-party websites set their effort levels via a Nash game. Demand for each customer class at each period is assumed to be a linear function of the price plus a

random term. The proposed unified model enables to analyse the three strategies in a multi-period problem environment. An extensive numerical study is designed to observe the effects of multiple night stays, hotel effort level and the hotel capacity on the decisions and the hotel profit. It is observed that the value of capacity rationing as a strategy increases with multiple night stays. However, effort levels of the third-parties in the second period are decreasing with multiple night stays. As capacity increases the hotel tends to decrease the price for the high priority class in both periods although the relation between price for the low priority class and hotel capacity is not monotone.

2 - Revenue for airlines: estimation and sensitivity
Sébastien Deschamps, Frédéric Meunier, Axel Parmentier

Estimating the revenue generated by a flight program is a central problem for an airline. Two aspects make the problem difficult. First the behavior of consumers needs to be modeled, in order to predict which itineraries will be bought and in which quantity. Second, as itineraries consume a common resource (the seats on the flight legs), selling one has an influence on the sells of others.

The Revenue Management literature provides accurate models to deal with those challenges when the purpose is to model revenue on a single origin-destination, but they become intractable when a full network is considered. Designing good schedules requires to solve such problems within a few seconds, and approximation models are available in the literature. We are interested here in a linear approximation called the Sales Based Linear Program (SBLP) which gives a good approximation of the revenue of an airline.

We propose an efficient way to solve the primal version of the SBLP through column generation. Dual solutions are the basis of a sensitivity analysis of the revenue, which can be interesting for an airline. Yet, reconstructing the duals from our column generation approach is not immediate. We extend our approach to generate an optimal dual solution. The overall method provides thus a quick revenue estimation and clues of possible improvements. The resulting algorithm is faster than the direct linear program resolution with a commercial solver.

3 - Reductions of Non-Separable Approximate Linear Programs for Network Revenue Management
Simon Laumer, Christiane Barz

For the classic network revenue management problem with independent demand, we extend the work of Vossen & Zhang (2015) on compact reductions of approximate linear programs (ALP). To capture the dependence between some of the resources, we keep these resources non-separable and complement the approximation with affine linear or separable piecewise linear basis functions. More precisely, we partition the network into several subnetworks, for which the approximate value function is either exhaustive, separable or affine linear. If the number of subnetworks which are not approximated affine linearly is equal to one, we prove a reduction which breaks the curse of dimensionality in the product space and the separable subnetwork. For the general case, we first prove a reduction which breaks the curse if dimensionality in the separable subnetworks before we suggest a heuristic reduction in the product space. We investigate how the tightness of the upper bound associated with different non-separable partitions correlates with certain features of such partitions. We thus suggest a measure which helps determining useful partitions. We illustrate our novel upper bounds and competitive policies in numerical examples.

4 - Standardized Cargo Network Revenue Management with Dual Channels under Stochastic and Time-dependent Demand
Lama Moussawi-Haidar, Walid Nasr, Maya Jalloul

We consider the network resource allocation problem, faced by sea freight operators, for standardized cargo transportation networks with time-dependent and stochastic demand. Standardized cargo capacity is sold through allotment contracts and on the spot market. The objective is to decide on the allotment contracts to select at the beginning of the booking horizon, as well as investigate dynamic booking control policies based on which spot market requests are accepted (booked) over the booking horizon before departure. This problem is formulated and solved in two stages: In the first stage, the allotment selection problem is formulated as an integer program in which the objective is to maximize the expected profit generated from the realized utilization of each resource in the network. The optimal solution to the allotment selection problem becomes the input to the spot booking control problem in the second stage. We formulate the spot booking problem as a dynamic program, and provide an efficient heuristic as an alternative to the computationally prohibitive dynamic programming (DP) approach. The DP is solved optimally for a small-size problem and for a variety of numerical cases. For large size problems, heuristics are proposed and tested via simulation. Also extensive sensitivity analysis is performed to test the heuristics, gain managerial insights and provide practical recommendations.

■ WA-47

Wednesday, 8:30-10:00 - Virtual Room 47

Mixed-Integer equilibrium/complementarity problems

Stream: Mixed-Integer Nonlinear Optimization
Invited session
Chair: *Marina Leal Palazón*
Chair: *Steven Gabriel*

1 - A Penalty Branch-and-Bound Method for Monotone Mixed-Integer Linear Complementarity Problems
Lukas Winkel, Marianna De Santis, Sven de Vries, Martin Schmidt

Linear complementarity problems (LCPs) are well-studied, non convex feasibility problems. They require nonnegativity of both a vector and the image of said vector under an affine linear mapping. Additionally, they require that this vector is orthogonal to its image under that mapping. They occur in the modeling of equilibrium problems in economics, mechanics, and other applied fields, but also have important applications in mathematics itself. In some applications, such as equilibria in traffic networks and energy markets, additional integral conditions on some of the variables become relevant. The combination of complementarity and integrality conditions make it unlikely, that an arbitrary MILCP has a solution. For these infeasible problems approximate solutions are of interest. In this case, approximate solutions are points minimizing some measure of the violation of integrality and complementarity conditions. The only known solution method considering these approximate solutions for mixed-integer linear complementarity problems (MILCPs) is a MILP formulation with a big-M. We propose a reformulation with a non convex, non smooth objective function. Moreover, we propose a novel type of branch-and-bound method to solve this reformulation to global optimality that branches by adding different combinations of penalty terms to the objective function in the case of monotone MILCP. Therefore, we are able to find both approximate solutions and feasible points if there are any.

2 - On Continuous Reformulations for Binary-Constrained Mixed Complementarity Problems
Marina Leal Palazón, Steven Gabriel, Martin Schmidt

Some real-world problems that arise in engineering-economic systems such as energy markets, transportation networks, or supply chains can be modeled as mixed complementarity problems. These types of problems are challenging due to their nonconvex nature. Furthermore, in these applications, integrality conditions, or particularly binary constraints, need to be sometimes incorporated, making them even harder to solve. Mixed integer complementarity problems are usually solved in the literature recasting the complementarity conditions as disjunctive constraints using additional binary variables and big-M constraints. By contrast, in order to avoid the tractability and correctness issues of the mentioned reformulations, we propose purely continuous reformulations. We reformulate binary-constrained mixed complementarity problems by remodeling the binary conditions as complementarity constraints. We show some theoretical properties of the proposed reformulations and a numerical experiment conducted using local solvers. The numerical study reveals the usefulness of these continuous reformulations in terms of solution quality and solution times.

3 - Integrated optimal pricing, sizing, and location of electric vehicle charging stations
Miguel F. Anjos, Ikram Bouras, Luce Brotcorne, Alemseged Gebrehiwot Weldeyesus

We propose a bilevel optimization model to determine optimal pricing, sizing, and location of electric vehicle (EV) changing stations by taking into account the preferences of EV users. In the upper-level of the bilevel model, the service provider is in charge of making decisions on the size, location and pricing of the charging stations to maximize its profit. In the lower level, EV users select their preferred charging stations. We present two methods to solve the model, a KKT-based method and a cutting plane method. The cutting plane method can only solve small instances and is used to validate the KKT-based method. Computational experiments on randomly generated sets of instances demonstrate the insights obtained and the potential of this approach.

■ WA-48

Wednesday, 8:30-10:00 - Virtual Room 48

Modeling of uncertainty in natural gas markets (online)

Stream: Emerging technical and financial aspects of energy problems
Invited session
Chair: *Iegor Riepin*

1 - Modeling and Probababilistic Forecasting of Natural Gas Prices
Jonathan Berrisch, Florian Ziel

In this paper, we examine the problem of modeling and forecasting European Day-Ahead and Month-Ahead natural gas prices. For this, we propose two distinct probabilistic models that can be utilized in risk- and portfolio management. We use daily pricing data ranging from 2011 to 2020. Extensive descriptive data analysis shows that both time series feature heavy tails, conditional heteroscedasticity, and show asymmetric behavior in their differences. We propose state-space time series models under skewed, heavy-tailed distribution to capture all stylized facts in the data. They include the impact of autocorrelation, seasonality, risk premia, temperature, storage levels, the price of European Emission Allowances, and related fuel prices of oil, coal, and electricity. We provide a rigorous model diagnostic and interpret all model components in detail. Additionally, we conduct a probabilistic forecasting study with significance test and compare the predictive performance against literature benchmarks. The proposed Day-Ahead (Month-Ahead) model leads to a 13% (9%) reduction in out of sample CRPS compared to the best performing benchmark model, mainly due to adequate modeling of the volatility and heavy tails.

2 - European Natural Gas Infrastructure Expansion Planning: An Adaptive Robust Optimization Approach
Iegor Riepin, Matthew Schmidt, Luis Baringo, Felix Muesgens

In this paper, we apply Adaptive Robust Optimization (ARO) approach to address data uncertainty for transmission capacity planning problem in the European natural gas market. The ARO approach is promising in this application because the optimization problem is confronted with limited probability information about uncertainties inherent to natural gas markets and risk-averse investment decisions are preferable in the context of security of supply. Furthermore, the approach allows controlling the degree of conservatism of the solution and is computationally tractable both practically and theoretically. We use polyhedral uncertainty sets to capture correlations among possible realizations of demand and supply for natural gas within the European market until 2030. The resulting ARO model is structured as a three-level MILP problem. We use the concept of strong duality and a constraint-and-column generation algorithm (also known as primal Benders decomposition) to solve the model. Our discussion is focused on the transmission and LNG assets from the Projects of Common Interest list, which combined come at a cost of 14 billion EUR and would add 140 bcm capacity to the EU natural gas system. However, the projects' contribution to the security of supply is under debate-recent analyses see them as a potential overinvestment supported by European public funds. Our findings are relevant for both energy modelers and industry experts with an empirical interest in gas markets.

■ WA-49

Wednesday, 8:30-10:00 - Virtual Room 49

Analysing Queues: Approximations, Data Modeling

Stream: Performance Evaluation of Queues
Invited session
Chair: *Sarah Dendievel*

1 - Heavy-traffic approximation of Markov-modulated infinite-server queueing system
Ankita Sen, Selvaraju Natarajan

In many real applications of large-scale queueing system, the interarrival times or the adjacent service times are correlated and modelling such queueing system with Markov modulated birth- death process has been quite appreciated by researchers. In this talk we present a heavy-traffic approximation of an infinite-server queueing system acting under Markovian environment with rapid switching, which indicates that the arrival rate and service rate are both determined by time and the state of an independently involving finite-state Markov chain, occurring at that certain time. However, extension of time dependency on modulated arrival rates and service rates has not been widely analysed in the literature. We will provide the fluid approximation and diffusion approximation of the queue length process of such queueing system, under heavy-traffic regime, and compare the fluid limit and diffusion limit with general infinite-server queueing system with i.i.d arrival process and service distribution. In addition, the performance measures of the diffusion limit process is presented to get an insight view of the limit process modulated by the external Markov process.

2 - Optimization of traffic control in multi-server priority queueing model with Phase type retrial and preemptive repeat policy
Raina Raj

We propose a MMAP [2]/PH [2]/S priority queueing model with with phase-type (PH) distributed retrial times. The arrival of incoming calls, i.e., handoff call and new call follow marked Markovian arrival process (MMAP). An arriving new call will be blocked when all the channels are occupied and consequently will join the orbit (virtual space) of infinite capacity. This blocked call will retry after some time following PH distribution. An arriving call will be blocked when all the channels are occupied by handoff calls only. The arriving handoff call will be provided service if at least one of them is serving a new call. The new call will be pushed out from the service and will join the orbit. The behaviour of model is described by level dependent quasi birth death process and analysed by applying matrix analytic algorithm. A traffic control optimization problem has been proposed and solve by applying different heuristic algorithms.

3 - A Two Class Discrete-Time Queueing Model with Bounded Variable-Length Service Times
Sarah Dendievel, Herwig Bruneel, Joris Walraevens

We consider a queueing model with one single infinite waiting room, two servers with bounded variable-length service times and two classes of customers, each having their own dedicated server. The classes of two consecutive customers arriving in the waiting room are dependent in a Markov way: two consecutive customers belong to the same class with probability p. This type of dependence is called interclass-correlation in the arrival stream. Customers are served on a first-come, first-served basis. This may cause a blocking effect: a class clustering in the arrivals may block customers of the other class arriving later in the waiting room regardless of the state of the other class' server. In the recent literature on discrete-time multi-class queueing models, deterministic service times and geometric service times have been considered. Solutions are obtained for these models with a probability generating function approach. However, the analysis developed for these cases does not seem to be suitable for bounded variable-length service times. In this talk, we present a matrix-analytic method to analyze the impact of the cluster parameter p on the performance of the queueing system. We illustrate our results with numerical examples.

■ WA-50

Wednesday, 8:30-10:00 - Virtual Room 50

Artificial Intelligence (AI) Research and Applications in Major Industries

Stream: OR for intelligent Energy Services
Invited session
Chair: *Spyridon Mouzakitis*
Chair: *Haris Doukas*

1 - I-NERGY: Delivering the next-generation Artificial Intelligence services for the Energy Sector
Georgios Lampropoulos, Sotiris Pelekis, Vagelis Karakolis, Gerasimos Anastasatos, Georgios Kormpakis, Ioannis Tsapelas, Spyridon Mouzakitis, Vangelis Marinakis, John Psarras

Artificial Intelligence (AI) is expected to radically reshape the energy sector value chain, by improving business processes performance, while increasing environmental sustainability and propagating high social value among citizens. Additionally, a vast amount of energy data is available, coming from several sources including smart grid sensors, simulators and open data sources. However, the energy sector is characterised by uncertain business cases, fragmented regulations, immaturity of standards and lack of high-end ICT workforce of EPES stakeholders. Additionally, the lack of interoperability across data stream providers, of energy data ownership and sharing, and of a holistic, safe and cooperative AI perspective amongst the EPES community actively hinder the effective integration of AI services in the sector. This publication presents the I-NERGY modular framework for supporting AI-on-Demand in the energy sector by capitalising on state-of-the-art AI, including resources of the AI4EU platform, as well as IoT, data analytics, adaptive learning and digital twin technologies. The solution, developed within the EU funded I-NERGY project, will enable AI-based cross-sector multistakeholder analytics tools for integrated and optimised smart energy systems management, based on interoperable data exchange. The project will also manage Open Calls for the delivery of innovative AI-driven energy services through the provisioning of financial support to third parties.

2 - Enabling Maritime Digitalisation through the use of extreme-scale Artificial Intelligence services
Ioannis Tsapelas, Georgios Kormpakis, Christos Tsapelas, Georgios Lampropoulos, Spyridon Mouzakitis, Dimitrios Askounis

Shipping is facing escalating pressure for safety, energy efficiency improvement and emissions reduction, as one of the leading sources of greenhouse gas and one of the high-incident domains, due to heavy traffic especially in congested waters. An extremely large amount of data, which is constantly produced by shipping, remains untapped due to the involvement of big stakeholders and the sophistication of modern vessel design and operation. Aiming to address those challenges, VesselAI will develop, validate and demonstrate a unique framework in order to exploit the potential of extreme-scale data and advanced HPC, AI and Digital Twin technologies. Hence, the adoption and application of Big Data driven technologies and practices will be promoted in maritime industry and beyond. Combining Digital Twin technologies, VesselAI focuses on the fusion of huge amount of data, coming from observations and simulations, to achieve highly accurate modelling, estimation of design and operation of ships under dynamic conditions in near real time. This publication presents the VesselAI project, which aims to address the challenges of implementing extreme-scale analytics in the maritime industry and to showcase how AI, cloud computing and HPC can encourage and enable deeper digitalization in this area. The technical enhancements and practical performance improvements which will be developed in the context of the EU funded VesselAI project, will be demonstrated in 4 maritime industry pilots.

3 - AI-based crop yield forecasting in Precision Agriculture
Konstantinos Latanis

Nowadays, the domain of precision agriculture is continuously gaining momentum as farmers have started adopting cutting-edge IT technologies in order to cope with the demanding requirements of the food market. More specifically, one of the challenges that precision agriculture is eager to address is forecasting of crop yield in a systematic and timely manner. In this context, the present paper focuses on the design and validation of machine learning algorithms that are introduced by the CYBELE Analytics Framework towards achieving optimal monitoring of crop yields by analysing various parameters such as soil, crop seed and weather, subsequently producing accurate yield forecasts. The methodology for the selection of the most suitable ML techniques is described and the results from the training and execution of the analytical algorithms are outlined, denoting the adding value that can be derived from the CYBELE platform. The performance of such machine learning mechanisms is compared to the existing mechanistic WOFOST crop simulation model.

■ WA-52

Wednesday, 8:30-10:00 - Virtual Room 52

Financing Clean Energy

Stream: OR in Climate Policy and Planning
Invited session
Chair: *Charikleia Karakosta*
Chair: *Haris Doukas*

1 - Promoting Energy Efficiency Investments in Building Sector: A Stakeholder Consultation Approach
Aikaterini Papapostolou, Charikleia Karakosta, Diamantis Koutsandreas, Filippos Dimitrios Mexis, Haris Doukas

Energy efficiency (EE) is an integral part of global energy policy, since it is not only widely recognised as an effective means of reducing greenhouse gas emissions, but also ensures long term security of energy supply. Towards this direction, EE investments have a direct effect on reducing energy consumption, while also improving industrial competitiveness and driving economic growth. Nevertheless, despite the demonstrated economic potential and environmental benefits, EE investments are still below policy targets set. In order to successfully identify potential risks and boost the finance of attractive EE project ideas, relevant key actors should be addressed and engaged, while the type of effort and messages to be used for each target group should be analytically examined. The aim of this study is to analyse through a targeted questionnaire the behaviour mainly of project developers, financiers, investors regarding EE investments in buildings, identify relevant risks and evaluate the added value of such investments' implementation. One of the conclusions emerged is that financial and economic risks were rated as the most critical ones affecting the successful financing of EE investments in the building sector.

2 - Assessing the necessity for investments in energy efficiency through the Sustainable Development Goals.
Filippos Dimitrios Mexis, Aikaterini Papapostolou, Charikleia Karakosta, Haris Doukas

Investing in energy efficiency is one of the main priorities of European Union's energy and climate policy offering a variety of benefits, including reduced energy costs, reduced carbon emissions, improved security of supply and improved employment conditions. These benefits cannot always be easily measured, while they are rarely considered when assessing the feasibility of energy efficiency projects. Towards this direction, the United Nation's Sustainable Development Goals (SDG) require strategies that build economic growth and address a range of social needs, while tackling climate change. Thus, it is considered a high-priority to link energy efficiency with SDG since the broad promotion and implementation of energy efficiency measures could significantly improve several SDG indices at a country level. In the context of the presented study, primary energy efficiency sectors and measures have been identified for eight European case study countries, namely Bulgaria, Czech Republic, Germany, Greece, Italy, Lithuania, the Netherlands and Spain. In addition, SDG indices, associated directly or indirectly with the implementation of energy efficiency measures have been assigned to relevant sectors. The emerging typology has concluded in an overall ranking among the case study countries by calculating the SDG indices associated with each relevant sector, which depicts the needs of the country on energy efficiency investments.

3 - Fostering energy efficiency investments through risk assessment
Diamantis Koutsandreas, Nikos Kleanthis, Charikleia Karakosta, Haris Doukas, Alexandros Flamos

It is evident that energy efficiency (EE) investments are inherently risky. A growing body of literature has identified that this is due to the multitude of uncertainties associated with the future cash flows of EE projects, such as the price of energy and technology risk. Therefore, their risk evaluation becomes a complex procedure, while also some risk factors present a lot of difficulties to be assessed, such as missing information and subjectivity. Financial institutions avoid evaluating the presence and potential severity of EE risks in detail and especially for small scale projects, due to the entailed high transaction costs. As a consequence, EE projects tend to never get financed despite the fact that some of them have good properties and being profitable. Many studies exist that evaluate the impact of individual risk factors to the successful implementation of EE projects, such as the rebound effect, however, a considerable gap exists in the literature as regards the holistic risk evaluation of EE projects. This study tries to bridge this gap by proposing an analytical framework for evaluating the total risk of EE projects to fail meeting their predicted performance. In this respect, all the risk factors and uncertainties that can negatively affect the profitability of EE projects are identified and analysed, while a mix of quantitative and qualitative techniques is utilised. The methodology is applied to the main EE sectors and several Member States.

4 - A multi-methods framework for profitability assessment of energy efficiency investments under uncertainty
Nikos Kleanthis, Diamantis Koutsandreas, Charikleia Karakosta, Haris Doukas, Alexandros Flamos

Mainstreaming energy efficiency (EE) investments requires to persuade investors regarding their profitability potential. However, EE investments are subject to various risks, which may affect involved actors' profits and create uncertainty. In this regard, a methodological framework for profitability assessment of EE investments under uncertainty is necessary to support their investment decisions. The methodological framework is based on a multi-methods approach, combining: financial analysis of EE investments using the Project Internal Rate of Return (IRR), risk assessment through quantitative and qualitative techniques, and analysis of investors' preferences in terms of minimum required return and maximum accepted holding period. Utilising this framework, investors can identify whether investigated EE investments can be profitable and their profitability level. In the context of this study, the methodology is applied to financial data for EE investments implemented in Germany, retrieved from the De-risking Energy Efficiency Platform (DEEP) database, an open-source database for EE investments performance monitoring and benchmarking. The results indicate that (i) investments realised in the industrial sector of Germany financially outperform those in the buildings sector, (ii) macroeconomic risk is a significant factor with regards to the uncertainty of EE investments, and (iii) separate investor profiles entail different preferences under distinct risk levels.

■ WA-53

Wednesday, 8:30-10:00 - Virtual Room 53

Equilibrium and Optimal Strategies in Queues

Stream: Queues with Strategic Customers
Invited session
Chair: *Rob Shone*

1 - An optimal mechanism charging for priority in a queue
Moshe Haviv, Eyal Winter

We derive a revenue-maximizing scheme that charges customers who are homogeneous with respect to their waiting cost parameter, for a random fee in order to become premium customers. This scheme incentivizes all customers to purchase priority, each at his/her drawn price. This is repeated for the case where customers are heterogeneous. The mechanism are based on the fact that once some customers get priority, its value of the other get even higher.

2 - A 3-player game theoretic model of a choice between two queueing systems with strategic managerial decision making
Michalis Panayides, Vincent Knight, Paul Harper

The main focus of this research is the construction of a 3-player game theoretic model between two queueing systems and a service that distributes individuals to them. The resultant model will then be used to explore dynamics between all players.

The first aspect of this work is the development of a queueing system with two consecutive waiting spaces. The strategic managerial behaviour corresponds to how individuals use these waiting spaces. Two modelling techniques were used: discrete event simulation and Markov chains. The state probabilities of the Markov chain system have been used to extract the performance measures of the queueing model (e.g. mean time in each waiting room, mean number of individuals in each room, etc.).

A 3-player game theoretic model is proposed between the two queueing systems and the service that distributes individuals to them. In particular this can be seen as a 2-player normal-form game where the utilities are determined by a third player with its own strategies and objectives. A backwards induction technique is used to get the utilities of the normal-form game between the two queueing systems.

This particular system can be applied in a healthcare scenario where it captures the emergent behaviour between, for example, the Emergency Medical Service (EMS) and the Emergency Department (ED). This will be used to investigate the impact of target measures on patient welfare.

3 - Analysis of an M/M/1 queue with deterministic idle time and busy period bound
Maayan Eyal, Yoav Kerner

We study a production system operates as an M/M/1 queue. After working continuously for a predetermined period, the server goes down for a time unit. We analyze the system's performance, using tools from time-dependent behavior of M/M/1. We discuss the optimal control policy under various cost function. In this paper, we consider a M/M/1 queueing system with a constant length of the busy period. We provide analytical and numerical procedures that compute the steady-state distribution, the optimal constant time limit, and the analytical and numerical analysis of lead time.

4 - Heuristic and reinforcement learning methods for admission and routing control in a queueing system with multiple heterogeneous facilities
Rob Shone, Vincent Knight, Paul Harper

Methods for optimising measures of social utility in queueing systems usually require interventions to be made in order to prevent customers from pursuing their own narrow self-interest. In this talk we consider a multiple-facility queueing system with both admission and routing control. The facilities are heterogeneous, with different server capacities, service rates and cost-reward structures, and we define a "socially optimal" policy as one that maximises the long-run average net reward per unit time. Although such policies can theoretically be found using stochastic dynamic programming, examples can be found which show that they may possess surprising and counter-intuitive properties, and thus there are very few general structural properties that can be proved.

It is possible, however, to show that the set of positive recurrent states under a socially optimal policy is contained within the corresponding set of states under a "selfish" policy. This has useful implications for computational algorithms, although we still encounter the "curse of dimensionality" in problems with a large number of facilities. For larger problems, we discuss the use of various heuristic methods, including those derived from optimal solutions to multi-armed bandit problems. We also consider reinforcement learning methods, in which progressive value function estimates are obtained by simulating the random evolution of the system.

■ WA-55

Wednesday, 8:30-10:00 - Virtual Room 55

Data-driven decisions in OR

Stream: EURO Working Group Data Science meets Optimisation
Invited session
Chair: *Hatice Calik*
Chair: *Victor Bucarey*

1 - Monte Carlo tree search for combinatorial optimization
Jorik Jooken, Pieter Leyman, Patrick De Causmaecker, Tony Wauters

Monte Carlo tree search is a popular algorithm in the field of game playing that learns to play good moves by running Monte Carlo simulations. In this presentation we will present our recent work which shows that an adaptation of Monte Carlo tree search can also be successfully used for a very different purpose, namely to solve combinatorial optimization problems. In such problems, the search space tends to be much larger than in a typical game. We propose various enhancements that rely on exploiting the combinatorial structure of the problem to tackle this challenge. The developed algorithm was evaluated on two different combinatorial optimization problems: the 0-1 knapsack problem and the quay crane scheduling problem with non-crossing constraints. The computational results reveal that the algorithm is able to compete with the state-of-the-art methods for both problems.

2 - A hybrid Mixed Integer Programming and automatic Tree Search algorithm for the Nurse Rostering Problem
Ziyi Chen, Patrick De Causmaecker

The Nurse rostering problem (NRP) needs to fully consider the preferences of nurses, legal constraints and other constraints, to formulate a systematic and scientific nurse scheduling plan. The problem aims to optimize the allocation of human resources, effectively reduce the nurses' work pressure and improve their work efficiency and quality. Due to the need to consider various constraints during the scheduling process, the NRP is complicated and is known to be NP-hard. Our research explore the possibility of producing feasible solution automatically. We aim at learning a policy that generalizes across NRP with different sizes and design a hybrid algorithm used to solve general NRP. We construct a feature vector to describe heterogeneous NRP solutions. And use it to substitute the solution matrix in the search process. After generating the initial solution, it will be improved by the fix-violation rules. In the process of improvement, our model can help to decide which branch to explore next and which branch to prune based on the learned selection policy and pruning policy, so as to quickly approximate the local optimal solution and reduce the solution space. After a local optimal solution is found, the method will reconstruct the structure of the current solution with an embedded Mixed Integer Programming (MIP), thereby quickly jumping out of the local optimum, and also enhancing the diversity of the search process and the possibility of finding the optimal solution.

3 - Learn-n-Route: Learning implicit preferences for vehicle routing
Rocsildes Canoy

We investigate a learning decision support system for vehicle routing, where the routing engine learns implicit preferences that human planners have when manually creating route plans (or routings). The goal is to use these learned subjective preferences on top of the distance-based objective criterion in vehicle routing systems. This is an alternative to the practice of distinctively formulating a custom VRP for every company with its own routing requirements. Instead, we assume the presence of past vehicle routing solutions over similar sets of customers, and learn to make similar choices. The learning approach is based on the concept of learning a Markov model, which corresponds to a probabilistic transition matrix, rather than a deterministic distance matrix. This nevertheless allows us to use existing arc routing VRP software in creating the actual routings, and to optimize over both distances and preferences at the same time. For the learning, we explore different schemes to construct the probabilistic transition matrix that can co-evolve with changing preferences over time. Our results on a use-case with a small transportation company show that our method is able to generate results that are close to the manually created solutions, without needing to characterize all constraints and sub-objectives explicitly. Even in the case of changes in the customer sets, our method is able to find solutions that are closer to the actual routings than when using only distances.

■ WA-58

Wednesday, 8:30-10:00 - Virtual Room 58

Operating Room Planning and ICU Management

Stream: ORAHS: OR in Health and Healthcare
Invited session
Chair: *Janis Sebastian Neufeld*

1 - Master surgery scheduling in operating rooms: comparing static and flexible approaches
Mariana Oliveira, Filippo Visintin, Daniel Santos, Inês Marques

Surgical waiting time targets are increasingly difficult to comply with due to management challenges such as rising demand and lack of resources. In particular, tactical decisions concern splitting available operating room time among surgical specialties. In practice, those decisions are often fixed and are seldomly revised based on demand and supply changes. In this talk, a combination of a mixed integer programming model that optimizes schedules and of a simulation approach to model demand levels is presented. This framework aims to generate long planning horizon dynamic master surgery schedules. By assigning more time to specialties with higher time demand, this work proposes a static, a long-term flexible and rolling horizon approaches to be compared with a real hospital case scenario. The comparison regarding waiting time, tardiness and throughput shows that all three proposed approaches outperform the real case setting. Moreover, among the three proposed approaches, the solution for the rolling horizon model led to a better performance, while the static version led to the worst one.

2 - Optimization for surgery department management: an application to a hospital in Naples
Andrea Mancuso, Adriano Masone, Francesco Messina, Mara Morra, Antonio Sforza, Claudio Sterle

Healthcare management is a widely investigated research topic in OR literature. Among the others, great relevance has been given to the problem of optimizing the activities of the hospital surgery departments to ensure an effective and efficient usage of the operating rooms. This work arises from the research agreement between Department of Electrical Engineering and Information Technology of University 'Federico II' of Naples and the 'Betania Evangelical Hospital (BEH)', a small hospital in Naples. It is focused on the application of OR methodologies to support the BEH surgery department operating rooms. Given the BEH surgery department comprising several specialities which share a given number of operating rooms, we tackle the problem of determining the assignment of rooms and dates to a set of elective patient surgeries over a predefined planning horizon and, simultaneously, defining the scheduling of the surgeries of each day and room. The problem has been modelled by an ILP formulation derived from literature, taking into account different objective functions dealing with patient throughput and emergency, surgery complexity and postponements and personnel exploitation. The proposed formulation has been tested on several scenarios derived from real data provided by the hospital. Moreover, different speciality-to-room assignment policies have been analysed to provide useful managerial insights for effective usage of the hospital resources.

3 - Machine Learning in the planning and flow of surgical patients: A state of the art
Santamaria-Acevedo Gustavo

Hospitals, and specifically operating theaters, are subject to high levels of variability in their operations, which makes it a very complex endeavor to predict the behavior of variables and performance measures that are essential for the optimal performance of the hospital. This variability is generated not only by the multitude of processes performed, and the heterogeneous agents involved, but also by the diversity of the patients and their characteristics, as well as those specific to the surgical procedures or treatments. In order to analyze this variability and to predict more accurately what may happen during the stay of surgical patients in the hospital, techniques such as Machine Learning and Predictive Analytics are being increasingly used by researchers and practitioners, in order to achieve more accurate predictive models that allow healthcare managers to better plan and schedule resources and flows. This article aims to provide the reader with a state of the art on the question of how Machine Learning and Predictive Analytics have been used in recent years to improve the management and flow of surgical patients, and evaluate the literature based on the problem characteristics (e.g., performance measures analyzed, patient categories, hospital ward) and the technical characteristics (e.g., solution approach, type of analysis). Throughout the article we summarize the main trends in Machine Learning in patient flow and planning, and identify future research avenues.

4 - Multi-objective intensive care patient bed assignment in hospital networks
Janis Sebastian Neufeld, Alexander Blume, Franz Ehm, Udo Buscher

Intensive care units (ICUs) are part of the most important infrastructure for critically ill patients in hospitals. At the same time, ICUs are technologically demanding, very expensive and therefore a limited resource in healthcare systems. Furthermore, hospitals may be specialized on certain medical disciplines and have only particular equipment. This leads to the necessity of an efficient allocation of patients to ensure a suitable treatment. However, existing patient bed assignment approaches usually consider only individual hospitals. We propose a new mixed-integer programming model for hospital networks consisting of several ICU stations. Various relevant practical requirements for ICUs are integrated, such as infectiousness of patients, qualifications of nurses and different types of intensive care units as well as equipment. Based on real-world data, epsilon method is applied to analyze the impact of a joint planning in a hospital network compared to an individual bed allocation of each hospital. We can quantify and visualize the effects on the medical treatment of patients, their convenience and the utilization of ICUs for regular operation as well as in the case of a pandemic. The presented approach enables an efficient allocation of patients and can serve as practical decision support.

■ WA-60

Wednesday, 8:30-10:00 - Virtual Room 60

2D cutting and packing problems

Stream: Cutting and Packing
Invited session
Chair: *Francisco Parreño*

1 - A Fast Asymptotic Heuristic for the Two-Dimensional Bin Packing Problem
Torsten Buchwald, Guntram Scheithauer

We present new results for the two-dimensional bin packing problem. We show how the First-Fit Decreasing-Height (FFDH) heuristic for the two-dimensional strip packing problem can be adapted to the two-dimensional bin packing problem. Using this adapted heuristic we derive sufficient conditions which ensure that a set of items can be packed into a single bin. These conditions are used to create a new asymptotic algorithm for the two-dimensional bin packing problem. The idea of this algorithm is based on a paper of Epstein and van Stee, who presented an algorithm with asymptotic performance of 2.25. The new sufficient conditions enable us to create a new asymptotic algorithm having an asymptotic performance ratio of 2 and running time O(n log n).

2 - Improved dynamic programming algorithms for large-scale two-dimensional guillotine cutting
Claudio Sterle, Adriano Masone, Mauro Russo, Antonio Sforza

The unconstrained two-dimensional cutting (U2DC) problem consists in dissecting a rectangular sheet of material to extract an unlimited number of rectangular pieces with different size maximizing the achievable profit. The state of the art of the solving approaches for the guillotine U2DC problem is represented by dynamic programming procedures whose effectiveness and efficiency has been extensively proved on very large size problem instances. We explore improvements of the state-of-the-art dynamic programming procedures for the U2DC. First, we apply new options and conditions for existing anti-redundancy strategies. Second, according to the effort of the modern home CPU suppliers, we introduce a parallelization scheme to improve the performance by integrating several cores. These improvements allow to effectively reduce the computation time needed to optimally solve very large size instances, as well as provide the optimal solution for several previously unsolved instances, with a small percentage increase of memory requirements. Further, we propose an integrated strategy to combine dynamic programming procedures with lower and upper bounds. In particular, we exploit known and new lower bounds, as well as improvements of upper bounds present in literature. This integration allows also to transform the procedure into a heuristic algorithm. Finally, a proper set of experimental results is provided to validate the proposed improvements and future work directions are given.

3 - A two-stage stochastic programming approach for the Integrated Production Planning and Cutting Stock Problem under Uncertainty
Khadija Hadj Salem, Elsa Silva, José Fernando Oliveira, Maria Antónia Carravilla

Uncertainty on the Cutting and Packing problems has a limited research body compared to its deterministic counterpart. However, it is a challenging task when dealing with a real-life application. In this context, we consider the Integrated Production Planning and non-exact two-stage guillotine Cutting Stock Problem under Uncertainty applied to the home textile industry. Given a set of fabric rolls with predefined widths, a set of references, and a set of piece types, where each piece type has a rectangular shape with a specific width and length and a fixed demand to be respected, the problem aims to decide simultaneously with which widths the fabric rolls should be produced, the respective lengths, and to generate the corresponding cutting patterns to cut all demanded pieces. During the production process, uncertainty is related to the appearance of defects. The main objective function is to minimize the total production costs. A two-stage stochastic programming approach is proposed to deal with uncertainty. The first stage decides the production quantity of each fabric rolls and the cutting sequences. In the second stage, the model reacts to the uncertainty scenarios by adjusting the production level. The quality of the model is evaluated through computational experiments on randomly generated instances. The numerical results highlight the advantages of the stochastic programming model compared to the deterministic model.

4 - Mathematical models for a cutting problem in the glass manufacturing industry
Francisco Parreño, Ramon Alvarez-Valdes

The glass cutting problem proposed for the ROADEF 2018 challenge is a two-dimensional, three-stage guillotine cutting process, with an additional cut to obtain pieces in some specific situations. However, it is not a standard problem because it includes specific constraints. The sheets produced in the glass manufacturing process have defects that make them different and have to be used in order. The pieces to be cut are grouped into subsets and the pieces from each subset must be cut in order.

We approach the problem by developing and solving integer linear models. We start with the basic model, which includes the essential features of the problem, as a classical three-stage cutting problem. Then, we progressively add new conditions to consider the order in the stacks, the minimum waste produced by guillotine cuts, and the possibility of trimming in some specific cases. Finally, we deal with the existence of defects in the sheets. We propose the first integer linear model capable of working with trimming and defects. The results show that in most cases it is possible to obtain the optimal solution for small problems taking into account all the constraints of the real problem and that good feasible solutions are obtained for larger instances.

■ WA-62

Wednesday, 8:30-10:00 - Virtual Room 62

Mirjana Kljajić Borštnar

Stream: Keynotes
Keynote session
Chair: *Sarah Fores*

1 - Enhancing organizational learning with AI
Mirjana Kljajić Borštnar

Decision making in an organizational setting is a complex process involving a group of people from interdisciplinary fields and in different roles. In the "data-driven" paradigm (from data-driven organization to data-driven innovation to data-driven decision making), it is suggested that data can add value to the organization. However, in many cases we have observed that this is not the case. Data Analysts and Data Scientists are not the only ones who can turn data into value. It is the understanding of complex organizational processes and ill-defined problems that, along with sophisticated data analytics, can transform data into business value and advantage. We derive our thesis from the idea that complex organizational problems can be efficiently supported by data analytics if the following conditions are met: 1) data analytics is driven by well-defined problems - the right questions are asked, 2) we have high quality data, and 3) data-driven models are well understood and thus support organizational learning. To illustrate our assumptions, we will present three real-world use cases of machine learning model implementation: 1) business-to-business sales prediction, 2) terminal call rate prediction during warranty period, and case 3) classification of older electronic texts in Universal Decimal Classification.

Wednesday, 10:30-12:00

■ WB-01

Wednesday, 10:30-12:00 - Bulding A, Amphitheatre

Queues with Strategic Customers II

Stream: Queues with Strategic Customers
Invited session
Chair: *Yoav Kerner*

1 - Strategic behavior in ticket queues with non-negligible clearance time
Yoav Kerner, Gal Sagi

In ticket queues, the absence of customer who balked is known only when those customers are being called for service. The existing literature assume that at that moment, such a customer is cleared in no time. Under this assumption, a threshold strategy is not a symmetric Nash equilibrium strategy. In this work we relax this assumption, by letting the clearance time to be exponentially distributed. We analyze the system's performance and show that the negative result regarding the Nash equilibrium holds when the clearance rate is large enough.

2 - Pricing and the Value of information in a Queue
Igor Rochlin, Yoav Kerner

Strategic customers base their decisions on the information they have. Sometimes, a preliminary decision is whether to acquire more information. In this paper, we study a model in which customers, upon arrival, decide whether to balk, to join or to purchase the information about the queue length. We obtain the customers' Nash Equilibrium given a fixed price of the information and then, being out main goal, find the optimal price that maximizes the revenue of the operator.

3 - Strategic behavior in queues with arrival rate uncertainty
Binyamin Oz, Refael Hassin, Moshe Haviv

We consider a general queueing model with a Poisson arrival process whose rate is random, and realized once for the entire process. We show that the distribution of the arrival rate at arrival instants is the size-biased counterpart of the original distribution. In particular, the ASTA (arrivals see time averages) property does not hold but rather a rate-biased version of it that we define and coin by the term RASTA (Rate-biased ASTA). We show that the RASTA phenomenon plays a crucial role in the analysis of strategic behavior of customers who evaluate the consequences of the actions they take upon arrival. We study such a system with a single server and strategic customers who decide whether to join or balk without observing the queue.

4 - Aggregating service provision for delay-sensitive customers towards supply chain coordination
Myron Benioudakis, Dimitris Zissis, Apostolos Burnetas, George Ioannou

We analyze the problems of double marginalization and supply chain coordination, as the manifest themselves in a make-to-order system with delay-sensitive strategic customers. Specifically, we consider a service provider who has to decide whether to provide a service directly to customers or use an aggregator's channel, who will be responsible for customer contact. In the first case the provider incurs a direct cost related to customer contact and charges customers with a retail price. When collaboration occurs, the provider charges the aggregator with a single price per served customer and the aggregator sets his own retail price.

We model the problem as a Stackelberg game between the provider and the aggregator under strategic customer behavior in an unobservable setting. We show that under the single price class of policies the resulting equilibrium is not generally socially optimal because of the double marginalization effect. However, channel coordination can be achieved without side payments between the two parties if the provider uses the aggregator's channel but also provides a direct compensation to the customers, proportional to the delay in filling the order.

We derive the pricing strategies under both single price and price/delay compensation schemes and determine conditions so that it is optimal for the provider to collaborate with the aggregator.

■ WB-02

Wednesday, 10:30-12:00 - Bulding A, Room A5

MCDA Methods 1

Stream: Multiple Criteria Decision Analysis
Invited session
Chair: *Eleftherios Siskos*

1 - On the Use of Reservation and Aspiration Points in Preference-based Evolutionary Multiobjective Optimization
Sandra González Gallardo, Rubén Saborido, Ana Belen Ruiz, Mariano Luque

Preference-based Evolutionary Multiobjective Optimization (EMO) algorithms approximate the region of interest (ROI) of the Pareto optimal front defined by the preferences of a decision maker (DM). In this work, we propose a preference-based EMO algorithm, called ERAL, at which the preferences are given by means of aspiration and reservation points. The aspiration point is formed by desirable values to be achieved by the objective functions, while the reservation point is constituted by objective function values not to be worsen. Internally, the first generations are performed using an initial set of weight vectors and the reservation point in the achievement scalarizing function proposed by Wierzbicki. Next, the weight vectors are updated according to both the aspiration point and the nondominated solutions generated so far, to re-direct the search directions towards the desired ROI. Finally, the remaining number of generations are run using the aspiration point and the new weight vectors. In addition, for these generations, we include in the algorithm the possibility of dynamically adapting the weight vectors also according to the shape of the ROI. To show the potential of our proposal, we perform computational experiments where we compare our algorithm with other well-known EMO algorithms, which include the preferential information as constraints in the problems. For this, we use benchmark problems with up to five objective functions.

2 - Analysis of the criteria interactions and their impact on the robustness of the decision model results
Eleftherios Siskos, José Rui Figueira, Peter Burgherr

Decision problems are often characterized by complex criteria dependencies, which can hamper the development of an efficient and technically sound multicriteria decision aid model. These dependencies, called criteria interactions, when still existent after the modelling procedure, have usually the form of either redundancy or synergistic effect between the evaluation criteria. The effort for their quantification requires arduous and demanding preference statements by the decision-maker and can nevertheless degrade the robustness of the model's results or worse lead to unexpected results and an unacceptable decision model. This research work attempts to analyse the behaviour of criteria interactions and examine their impact on the assessment of a decision model and the calculation of its results. Towards this direction, various criteria interaction instances are analysed and tested on differently sized evaluation problems. The results are obtained using a preference elicitation framework, based on the Simos method, and the application of the Choquet integral. They are then stress-tested with regard to their robustness, with the aid of Robust Ordinal Regression techniques. The overall objective of this research work is to shape robustness rules and provide recommendations and guidelines for analysts and practitioners, who want to accommodate interacting criteria in their evaluation problems.

3 - Preference disaggregation: a probabilistic view
Mohammad Ghaderi

Preference disaggregation concerns the construction of value functions from the preference information supplied by a decision-maker, typically in the form of qualitative judgements and holistic pairwise comparisons of decision alternatives. From a methodological perspective, similar to discrete choice analysis and choice-based conjoint analysis, preference disaggregation combines the input information with assumptions to identify the relationships between a set of preferentially relevant variables, i.e., decision criteria, and observed choices, i.e., reflected preferences, via constructing interpretable value functions. Unlike the traditional econometric methods of discrete choice analysis, preference disaggregation analysis circumvents restrictive specification and distribution assumptions by formulating the problem of parameters estimation as a constrained optimization problem. From this perspective, a drawback of this class of methods is the deterministic outputs that they produce and a lack of concrete theoretical basis to account for the imperfect knowledge of the problem from the analyst's point of view. I attempt to fill this gap by introducing a generalized preference disaggregation framework that adopts a probabilistic view for addressing the analyst's lack of complete information.

4 - Comparing approaches to assess the final ranking of alternatives actions in extrapolation phase of MC Disaggregation - Aggregation methods
Athanasios Spyridakos, Nikos Tsotsolas, Isaak Vryzidis

The extrapolation of the Multicriteria Disaggregation - Aggregation UTA Methods concludes to the ranking of the total set of alternative actions based on a working additive value preference model which is the barycenter of the n-dimensional hyper-polyhedron bordering the compatible solutions of the MC Linear problem. Since there are rank reversals of the alternative actions of the total set for the different points of the n-dimensional hyper-polyhedron which is strong occurred in low robustness cases, this work proposes a set of indices for measuring the rank reversals of the alternative actions and examines the appropriateness of the Barycenter as a working additive value preference model instead of utilizing the different rankings coming from the systematic exploration of the hyper-polyhedron. The systematic exploration of the n-dimensional hyper-polyhedron can be effectively implemented using the tomographical approach and the aggregation of the different rankings can be achieved by the utilization of the techniques of the social choice theory such as the De Condorcet, Dodgdson, Eigenvector and Cook and Sheiford methods. This comparative analysis is illustrated through a case study where the aggregated rankings and the rank reversals are analyzed providing a methodological frame to measure the level and the impacts of the low robustness cases.

■ WB-03

Wednesday, 10:30-12:00 - Bulding A, Room 3A

Machine Learning and Combinatorial Optimization II

Stream: Combinatorial Optimization
Invited session
Chair: *Gianni A. Di Caro*
Chair: *Matteo Salani*

1 - Using denoising autoencoder LSTM networks to balance exploration and exploitation in estimation of distribution genetic programming
David Wittenberg, Franz Rothlauf

Estimation of distribution genetic programming (EDA-GP) algorithms are metaheuristics for variable-length combinatorial optimization problems that replace the standard recombination and mutation operators of genetic programming (GP) by sampling from a learned probabilistic model. An example of an EDA-GP is DAE-GP that uses denoising autoencoder long short-term memory networks as probabilistic model. DAE-GP is the first and only EDA-GP that uses neural networks as a model and outperforms standard GP. The key advantage of DAE-GP is that we can flexibly identify relevant relationships between problem variables and that we can apply denoising on input candidate solutions to control the generalization behavior of the model. However, current work only uses subtree mutation with fixed corruption strength. In this work, we therefore study alternative denoising strategies. We show on standard GP benchmark problems that denoising strongly influences the exploration and exploitation behavior in search. Adjusting the denoising strategy can therefore help to either exploit promising areas of the parent population or to explore new search spaces.

2 - Predictive analytics for real-time auction bidding support: a case on fantasy football
Vittorio Maniezzo, Fabian Andres Aspee Encina

This work reports about an end-to-end business analytics experiment, applying predictive and prescriptive analytics to real-time bidding support for fantasy football draft auctions. Forecast methods were used to quantify the expected return of each investment alternative, where Sharpe ratio as borrowed from finance is used to compensate expected performance with past irregularity. Both statistical and neural regression models have been tested, and integrated with subgradient optimization of the Lagrangian relaxation of the investment problem, to provide adaptive online recommendations on the allocation of scarce budget resources. A distributed front-end implementation of the prescriptive modules testifies the viability of this architecture for actual support.

3 - Two-stage optimization framework for Routing and Spectrum Assignment in Elastic Optical Networks
Matteo Salani, Cristina Rottondi, Leopoldo Cerè, Massimo Tornatore

Machine Learning (ML) has been widely investigated in the field of optical networking as a promising methodological approach to tackle several network operation tasks, including Quality of Transmission (QoT) estimation. Though the research community has thoroughly investigated ML-based frameworks to accomplish specific prediction tasks, integrating such predictions in Routing and Spectrum Assignment (RSA) models and policies is an open research problem, still in its infancy.

In this paper, we propose a framework for optimal RSA planning that incorporates the QoT estimations provided by a ML regressor to define the lightpaths' reach constraints in an Integer Linear Programming (ILP) formulation for a flexi-grid optical network. The framework devises a two-stage iterative procedure: the first phase minimizes the overall spectrum occupation, whereas the second phase maximizes the minimum guardband size between neighbor channels, without increasing the overall spectrum occupation obtained in the previous phase. Moreover, after the second phase, reach constraints are added based on the outcome of the previous optimization round, in order to exclude from the set of feasible solutions those lightpaths that exhibited unacceptable. In our performance assessment, the proposed framework achieves spectrum occupation savings up to 48.1% (around 33% on average) in comparison to traditional ILP-based RSA approaches with reach constraints computed leveraging margined analytical models.

■ WB-04

Wednesday, 10:30-12:00 - Bulding A, Room 3B

Maritime planning and logistics

Stream: Routing, Logistics, Location and Freight Transportation
Invited session
Chair: *Bernardo Martin-Iradi*

1 - A bi-criteria moving-target traveling salesman problem under uncertainty
Markku Kallio, Alaleh Maskooki

This article concerns a variant of moving target traveling salesman problem where the number and locations of targets vary with time and realizations of random trajectories. Managerial objectives are to maximize the number of visits to different targets and to minimize the total travel distance. Employing a linear value function for finding supported Pareto-efficient solutions, we develop a two-stage stochastic programming model. We propose an iterative Randomized Dynamic Programming (RDP) algorithm which converges to a global optimum with probability one. Each iteration in RDP involves a randomized backward and forward recursion stage as well as options for improving any given schedule: swaps of targets and optimization of timing for visits. An integer linear programming (ILP) model is developed to evaluate the performance of RDP against a standard ILP solver on instances of real data for scheduling an environmental surveillance boat to visit ships navigating in the Baltic Sea. Due to a huge number of binary variables, the ILP model in practice becomes intractable. For small to medium size data sets, the Pareto-efficiency of solutions found by RDP and ILP solver are equal within a reasonable tolerance; however, RDP is significantly faster and able to deal with large-scale problems in practice.

2 - A beam search algorithm for solving the container premarshalling problem with crane time minimization objective
Consuelo Parreño-Torres, Ramon Alvarez-Valdes, Francisco Parreño

The Container Premarshalling Problem (CPMP) arises in the yard of container terminals before the arrival of a ship and makes it possible to reduce its berthing time and thus to increase container terminal efficiency. We study the CPMP with the objective of minimizing the time spent by the crane in transforming a bay into one without blocking containers. We propose a Beam Search (BS) algorithm integrating a constructive heuristic that completes solutions and a local search that, given a solution, tries to improve it. We explore several alternatives for the local and the global evaluation and assess the performance of our algorithm on well-known datasets. Comparing with the solutions proposed by other exact and heuristic methods, our algorithm reduces on average the crane time of the instances where the optimum was not found and achieves the optimum in almost all instances in a computational time of less than five minutes.

3 - The multi-port berth allocation problem with speed optimization: Exact methods and a cooperative game analysis
Bernardo Martin-Iradi, Dario Pacino, Stefan Ropke

In this study, we focus on a variant of the Berth Allocation Problem (BAP), which aims at assigning berthing times and positions to vessels in container terminals. The problem, known as the multi-port berth allocation problem (MPBAP) extends the BAP to cover multiple ports where vessel traveling speeds are optimized between ports, thus exploiting the potentials of a collaboration between carriers and terminal operators. Exploiting a graph representation of the problem, we reformulate an existing mixed-integer problem formulation into a generalized set partitioning problem where each variable refers to a sequence of feasible berths in the ports visited by the vessel. Integrating column generation and cut separation in a branch-and-cut-and-price procedure, the method is able to outperform commercial solvers in a set of benchmark instances and adapts better to larger instances. In addition, we apply methods of cooperative game theory for distributing efficiently the savings of a potential collaboration and show that both carriers and terminal operators would benefit from such collaboration.

■ WB-05

Wednesday, 10:30-12:00 - Building Δ, Room Δ105

Novel Methods in Optimization under Uncertainty

Stream: Stochastic and Robust Optimization
Invited session
Chair: *Martin Smid*

1 - Optimal Design of Controlled Environment Agricultural Systems Under Market Uncertainty
Shaylin Cetegen, Matthew Stuber

Controlled environment agriculture (CEA) presents significant opportunities for improved food security; however, formal assessment of the economic viability of CEA technology is required to further motivate its adoption. Since agronomic yield uncertainty is significantly reduced through the CEA growing model, market uncertainty arises as the dominant uncertainty source in CEA systems design. In this work, we present a novel methodology for the simultaneous robust design and scheduling of CEA systems under multi-period risk. This problem is formulated as a semi-infinite program with multiple semi-infinite constraints representing mean-variance risk exposure with uncertain covariance over each period in the planning horizon. The model is formulated generally and can be used to optimize large-scale CEA systems for cultivation of any crop portfolio under any number of cultivation modes. A solution to this model represents an optimal design and operating schedule that is robust to worst-case uncertainty, which provides a conservative basis for CEA engineering and investment decision-making. This methodology represents, to our knowledge, the first robust optimization approach to CEA systems and has been demonstrated herein to effectively increase the robustness of CEA systems to market uncertainty, improve the long-term economics of CEA systems over naïve operating strategies, and validate the economic viability of single and multi-mode CEA production of distinct crop portfolios.

2 - Solving Parametric Systems for Interval Linear Programming
Elif Garajová, Miroslav Rada, Milan Hladik, Jaroslav Horáček

Interval programming provides a mathematical tool for modeling uncertainty in optimization problems, for which only bounds on the exact data are available. In this talk, we address the problem of describing the so-called weakly optimal solution set of an interval linear program, i.e. the united set of all optimal solutions over all possible scenarios. We utilize a description of the optimal set derived from strong duality in linear programming, which leads to a parametric interval linear system. Since determining the exact interval hull of the optimal set was shown to be an NP-hard problem, methods that can provide a sufficiently tight approximation of the set are also of interest. Many of the existing methods approximate the possibly non-convex optimal set by an interval box, providing an enclosure that can often be highly overestimated. To avoid such overestimation, we introduce a branch-and-prune method for solving parametric interval linear systems that generates a union of interval boxes, which can better capture the non-convex nature of the set and thus provide a tighter approximation. Furthermore, we conduct a computational experiment to compare several pruning conditions that can be used to test infeasibility and feasibility of interval boxes within the branch-and-prune framework, based on interval linear algebra and on the geometry of zonotopes.

3 - Approximation of Multistage Financial Problems by Smoothed Quantization
Martin Smid

We present an approximation technique for solving multistage stochastic programming problems with Markov underlying stochastic process – the type of problem typically occurring in financial applications. The process is approximated by a discrete skeleton process, which is consequently smoothed down by means of the original unconditional distribution. Approximated this way, the problem is solvable by Markov Stochastic Dual Dynamic Programming. We state an upper bound of the nested distance of the exact process and its approximation and discuss its convergence in the one-dimensional case. Further, we propose an adjustment of the approximation guaranteeing that false arbitrage opportunities do not occur in the approximated problem. Finally, we apply our technique to a real-life production-emission trading problem and demonstrate the performance of its approximation given the "true" distribution of the random parameters.

4 - Assessing the choice of ambiguity set for distributionally robust portfolio selection in electricity spot markets
Anton Isopoussu, Andrew Rosemberg

Forecasting in environments involving high-dimensionality and non-stationarity results in highly noisy forecasts. This leads to decision making, such as bidding in the electricity markets, to be inherently risky. Selecting risk averse decision strategies which are robust to model misspecification is a key step in reduc- ing unexpected volatility in the chosen performance metrics and post-decision surprise. Distributionally Robust Optimization (DRO) is a technique that ad- dresses these issues by introducing the notion of ambiguity into the forecasts, and takes it into account in the decision making step by defining a min-max problem over the ambiguity set. Many types of ambiguity sets have been pro- posed in the literature, however there is little published work in showing how parameter selection for the ambiguity set should be done in applications. This work aims at closing this gap by evaluating previously proposed ambiguity sets and relevant parameter estimation methodologies.

■ WB-06

Wednesday, 10:30-12:00 - Building Δ, Room Δ103

Public transport II

Stream: Timetabling and public transport
Invited session
Chair: *Pieter Vansteenwegen*

1 - The pickup and delivery problem with on-line transfers
Paul Bouman, Gizem Ozbaygin, Lucas Veelenturf, Rick Willemsen

We introduce and study a new variant of the vehicle routing problem, which we call the pickup and delivery problem with on-line transfers (PDPOT), motivated by an innovative passenger transportation concept involving self-driving vehicles developed by Next future mobility. These vehicles are designed in a way that they can couple/decouple while en-route and transfer passengers seamlessly towards more efficient capacity utilization and traffic management. Due to the potential reduction in fuel/energy consumption and travel costs, there are studies in the vehicle routing literature taking transfer opportunities into account within their framework. The most closely related vehicle routing problem to the one we consider in this study is the pick-up and delivery problem with transfers. However, the main difference and perhaps the most challenging aspect of the PDPOT is that when two or more vehicles couple, the passengers may transfer from one vehicle to another during the time the vehicles are traveling together as a single vehicle. A major challenge is that it may be beneficial for vehicles to deviate from shortest routes in order to facilitate on-line transfers. Among the major contributions of our study are: (1) the development of an optimization based approach to solve a complex vehicle routing problem arising in an on-demand transportation system involving autonomous shared vehicles, and (2) we aim to analyze the benefits of on-line transfers in different environments.

2 - Capacity analysis of a large railway network
Pieter Vansteenwegen, Jolien Uyttendaele, Nikola Besinovic

This research considers a large and intensively used part of the Belgian railway network close to the central bottleneck of Brussels. This part contains around 165 km of tracks, 12 stations and 86 trains driving in different directions during the morning peak hours. The main questions are if this network is indeed used almost at full capacity, as assumed by the infrastructure manager, or if and how additional trains could drive through this network, as requested by an operator. The analysis starts from the current timetable and routing, but these might be modified if this would turn out beneficial for capacity usage. In order to analyze, and later modify, the capacity usage, results from quick and easy estimations, are compared to detailed calculations based on the well-known compression method and max-plus algebra. A number of challenges need to be addressed in order to apply the compression method to this large network. Since there is no resource in the network where all trains pass, appropriately ordering all trains is not straightforward. Moreover, some trains need to be split artificially for the ordering, while keeping the parts together in the compression method. Preliminary results show that with the current timetable and routing adding more trains would be difficult.

■ WB-07

Wednesday, 10:30-12:00 - Building Δ, Room Δ102

Data Envelopment Analysis

Stream: Data Envelopment Analysis and Performance Measurement
Invited session
Chair: *Ana Camanho*

1 - Efficiency and effectiveness improvement of wastewater treatment plants considering Emission Quotas
Flávia Barbosa, Ana Camanho, Alda Henriques

Wastewater treatment plants (WWTPs) constitute an important part of the urban water cycle's sewage system. They have the role of removing pollutants from wastewater to enable the safe disposal of the treated effluent in the natural environment. This work aims to contribute to the performance enhancements of WWTP through the assessment of their efficiency and effectiveness. The methodology used is based on Data Envelopment Analysis. Efficiency evaluates the ability of WWTPs to minimize energy consumption, given the effort for the removal of pollutants currently observed. Effectiveness evaluates the extent to which WWTPs could reduce energy consumption by meeting exactly the emission quotas specified by legislation. The empirical analysis evaluates WWTP from a Portuguese water company - Águas do Centro Litoral (AdCL). We explore two possible scenarios for performance improvement. The first assumes that pollutants emission quotas are fixed at each WWTP. The second assumes that emission quotas are fixed for the receiving waters (e.g. river or watercourse in the natural environment) according to the effluents' quality. Still, trade-offs in pollutants removal can be negotiated among WWTP. This second scenario requires a system-wide analysis to identify optimal targets for pollutants removed in each WWTP, located in the frontier of the production possibility set.

2 - Measuring dynamic inefficiency in the presence of corporate social responsibility and input indivisibilities
Magdalena Kapelko, Alfons Oude Lansink, Spiro Stefanou

This article proposes a model for evaluating inefficiency accounting for firms' corporate social responsibility engagement as part of their broader output production activities. The model combines the production of marketable outputs, socially responsible outputs, and undesirable outputs into overall measures of firm performance using data envelopment approaches. Methodologically, the article builds on the dynamic by-production model, which accounts for adjustment costs related with investments, allowing for non-convexities of the production set and input indivisibility, as well as firm corporate social responsibility activities. This study compares dynamic technical inefficiency scores for each input, output, and investment, estimated assuming the presence of input indivisibility (non-convexity) and its absence (convexity). The empirical application focuses on European firms in three industries (offering capital, consumption, and other goods) for the period 2010-2017. The results show significant differences between inefficiencies with and without the convexity assumption and find evidence for non-convexity of firms' production set and inputs' indivisibility. Overall, among all outputs, the results reveal the highest inefficiency in the production of socially responsible outputs.

3 - Internal benchmarking to assess the cost efficiency of a broiler production system: an application of data envelopment analysis inspired by throughput accounting
Ana Camanho, Fabio Piran, Daniel Lacerda, Maria Silva

Economic efficiency assessments based on Data Envelopment Analysis are scarce compared to technical efficiency studies, even in for-profit firms. Some aspects justify this scarcity, such as the difficulty to estimate accurate prices, given their variability over time. In many situations, external benchmarking is hindered due to organizations' unique nature and the barriers to sharing information considered critical to competitiveness. The use of internal benchmarking can overcome some of these difficulties. This study conducted an internal benchmarking analysis of a broiler production system, focusing on cost efficiency. We conducted longitudinal case-based research over six years (2014 to 2019). The concepts of throughput accounting of the Theory of Constraints were applied to structure the DEA model (inputs, prices, and output). The Critical Incident Technique was used to explore the effects of interventions on the production system's cost efficiency. The results show that the broiler production system could reduce 32% of the total cost per unit of production if the balance of inputs suggested by the DEA evaluation was used. This work contributes to the literature by showing the potential of internal benchmarking to explore the evolution of cost efficiency over time, and to measure the impact of management actions on performance, providing valuable information to guide continuous improvement.

■ WB-08

Wednesday, 10:30-12:00 - Building Δ, Room Δ101

Initiatives in OR Education 2

Stream: OR Education Initiatives
Invited session
Chair: *Milagros Baldemor*
Chair: *Gerhard-Wilhelm Weber*
Chair: *Alessandro Hill*

1 - Using linear goal programming approach and preference information to solve the classroom allocation problem in a Greek university: A robustness analysis
Nikos Tsotsolas, Zoi Markopoulou

The classroom allocation problem has been studied in several research papers during the last decades. However, the robustness issues that are arisen in such problems shall be studied more thoroughly in order to provide more accurate information to the decision makers. In this research work a 0-1 linear model is discussed based on a goal programming approach, which takes into consideration the expressed preferences of the schools or departments of a university concerning the time schedule during the day and the nominal capacity of the classrooms. The linear model includes an overall objective function minimizing the deviations from the given goals that express the specific preferences. It also includes four categories of constraints, namely: (1) preferences concerning daily time zones per school, (2) preferences concerning classrooms capacity per school, (3) the non-use of specific classrooms for each school and (4) the unique use of each classroom per time slot. Based on the resulting optimal solution, a robustness analysis approach is applied towards the discussion of multiple or near optimal solutions, which lead also to the estimation of relevant robustness indices. The whole approach was applied to the University of West Attica, with six schools and 104 classrooms to be allocated. The LP models were solved by using GEKKO Optimization Suite in Python.

2 - Expanding Students' Social Networks via Optimized Team Assignments
Alessandro Hill, Steffen Peuker

We present a novel method for assigning students to course project teams that is based on social network analysis and optimization. It is so important for the students' educational, personal, and professional success to collaborate within a strong and diverse peer network. Therefore, we aim at expanding the students' social networks through a grouping strategy that provides each individual maximal opportunity to establish new ties. In our data-driven approach, we suggest a process for surveying existing connections in the class social network. We show that the underlying difficult combinatorial problem, a variant of the so-called bin packing problem, can be formulated as an integer program and solved to optimality using mathematical optimization. Model extensions are discussed that account for high-density networks, team balancing, and mate forcing and forbidding, allowing for hybridization with existing grouping techniques. In an empirical study, we use 1-year data from 10 industrial engineering classes including 255 students and 77 project teams, in both modes face-to-face and virtual. We study potential and impact of our process, compared to commonly used random-assignment, self-selection, and clique-oriented grouping. The number of ties can be increased by an impressive 62% compared to only 17% when allowing students to self-assign. Moreover, student feedback strongly supports the usefulness of our idea for adaptive class management and student contentment.

■ WB-21

Wednesday, 10:30-12:00 - Virtual Room 21

Biases

Stream: Behavioral Decision Making
Invited session
Chair: *Linda Migliorati*

1 - Methods for reducing the belief perseverance bias
Jana Siebert, Johannes Siebert

The belief perseverance bias is responsible for sustainable perseverance of fake news (false news stories packaged and published as if they were genuine) in individuals' minds. The belief perseverance bias belongs to the group of motivational biases, which are difficult to correct. The experimental research on debiasing belief perseverance is quite limited. There have been only a few debiasing methods proposed so far and the research has focused primarily on investigating effectiveness of single debiasing methods. Due to the missing experimentally-driven comparisons of various belief perseverance debiasing methods within one experiment, there are only limited implications for practical applications in terms of which debiasing method to use in order to achieve the best debiasing effect. In our study, we develop two methods for reducing the belief perseverance bias and test them in an experiment together with another debiasing method already proposed in the literature. All three methods lead to a reduction in belief perseverance. The comparison of the methods in terms of their effectiveness shows that there are significant differences between the methods.

2 - Planning Fallacy in performing Academic and Nonacademic Tasks
Nadine Ayoubi

Planning Fallacy is a derived phenomenon from cognitive bias in behavioral economics and noticeable on daily basis, it can occur in small tasks like housework to big ones like construction projects and supply chain. It is defined as the tendency to underestimate the amount of time needed to complete a task despite the knowledge that a common prior experience took longer than planned, which leads to running behind schedule in project management. Previous researchers have proven that people generally underestimate the time by studies that concentrated on a certain perspective and expanded the knowledge there. This research will be based on experimental studies to examine this phenomenon in different methods of testing, each experiment has been designed for a different purpose, four experiments were conducted to see whether participants make overly optimistic predictions in both academic and nonacademic tasks. The academic part was applied to different students from "Azrieli College of Engineering Jerusalem" in which participants estimated how much time it would take them to complete academic tasks like (1) solving two calculus assignments- impractical task (2) performing laboratory experiments- practical task, and nonacademic (3,4) like playing a memory game and assembling jigsaw puzzle online on a program that was specifically designed and built for this study to test the accuracy of time estimation of random participants, not necessary students. The results of the

3 - What are the extent, causes and implications of preference change on stakeholder group-decision processes in the public sector?
Martijn Kuller, Philipp Beutler, Judit Lienert

MCDA can support complex public decision-making by integrating expert information with stakeholder preferences. As preferences are thought to be formed by the MCDA process, they can change over time. However, little is known about (1) the extent of change, (2) its causes and (3) effects on decision outcomes. We explored this in three case studies (CS): developing a flood forecast and early warning system for West Africa (CS1) and transitioning to decentralized wastewater systems in rural Switzerland (CS2, CS3). All CS collaboratively generated objectives, followed by fast preference elicitation through repeated direct ranking of objectives in consecutive workshops (measuring moments, MM) over several years. Rankings were compared, analysed over time and tested for their dependency on known personal characteristics and unknown latent variables. We calculated option rankings for each MM through MCDA, using rank sum weight estimates from objective ranks. We observed preference change for all CS, but only limited and inconsistent evidence for drivers of preference. While in CS1 change decreased with time, CS2 and CS3 exhibited an opposite trend. Concordance between participant rankings was always significant, but without a consistent trend over time. Despite the preference changes, MCDA-based option rankings were relatively stable, without relevant rank reversals for best- and worst ranked options. Thus, preference change was not substantial enough to change MCDA recommendations.

4 - Loss aversion bias and spatial decisions: insights from a behavioural experiment
Linda Migliorati, Valentina Ferretti

Prospect theory (Kahneman & Tversky, 1979) provides a well-known descriptive model for decisions under uncertainty, highlighting the importance of framing effects (whether a prospect is presented as a loss or a gain) and of loss aversion (the asymmetry between losses and gains, with the former looming larger than the latter). While the study of cognitive and motivational biases has led to a consolidated body of research in most scientific domains (e.g. economics, marketing, decision science, policy making, operational research, etc.), no attention has yet been paid to the same biases in the domain of spatial judgements and decision making processes. We believe that the spatial component often associated with both alternatives and evaluation criteria provides an interesting opportunity to investigate new dimensions of behavioural issues. The research questions underpinning our research are thus the following ones: (i) is there any evidence of loss aversion in decisions involving a spatial representation of impacts, i.e. maps? (ii) If there is evidence of loss aversion, is this effect consistent with Prospect Theory? Our study discusses the answers to these questions through the development of a behavioural experiment run in the laboratory with 172 participants and concerning the urgent issue of plastic pollution in the Oceans. The work is innovative as it represents one of the first studies aimed at testing the cognitive implications of map-mediated decision making processes.

■ WB-22

Wednesday, 10:30-12:00 - Virtual Room 22

General papers

Stream: Behavioral Operations Management
Invited session
Chair: *Katharina Burger*

1 - How should consumers judge the helpfulness of online reviews? A case study of car automotive marketing
Shanshan Huang, Cong Cao, Jun Yan, Mengxiang Li

Helpful online reviews (ORs) are crucial in e-commerce and play a key role in purchase decisions. Thus, identifying the factors affecting the helpfulness of ORs is the focus of current research. Previous work has failed to study ORs in a combination of online and offline shopping situations. This study was to determine the factors that influence the perceived helpfulness of ORs in the Chinese automobile sales market and then explore the mechanism of these specific factors. First, a group interview was organized to obtain relevant factors preliminarily. Second, with the structured data collected by questionnaire, partial least squares structural equation modelling (PLS-SEM) was adopted to assess these factors' influence on the helpfulness of ORs. Finally, one-on-one in-depth interviews were conducted to understand the mechanism involved. The preliminary results of the research show that ORs of different quality, from various channels, in dissimilar types of presentation significantly affect consumers' perception of the helpfulness of ORs. The study established an expanded model of the effect of the helpfulness of ORs to show more details. The model can further enhance ORs' understanding, which improves consumers' decision-making efficiency and improves enterprises' sales performance.

2 - Human-Robot collaboration in warehouse order picking: Relationship dynamics and behavioral implications
Alexandros Pasparakis, Jelle de Vries, René de Koster

Warehouse operations are rapidly becoming more robotized and one important way of working is in collaboration between robots and humans. By combining the flexibility of humans in performing complex tasks with the tirelessness of robots in performing repetitive tasks, human-robot collaboration is disrupting the traditional way of order picking. To prepare for this new reality, we conducted an experiment in a warehouse erected for this study to (i) compare the objective outcomes of productivity and accuracy in two collaborative setups with the human leading the robot versus the human supporting the robot, (ii) investigate the behavioral mechanism that governs the reaction of humans to the novel collaboration with robots. We find that the human leading is superior to the human supporting in terms of order picking productivity but inferior in terms of picking accuracy. We establish prevention regulatory focus as the behavioral construct through which workers may partially bridge the productivity gap between setups. Finally, we confirm that competence in manual order picking is directly transferable to the new human-robot collaborative environment.

3 - Preferences estimation under bounded rationality: Identification of attribute non-attendance using SVM.
Veronica Diaz, Ricardo Montoya, Sebastian Maldonado

There is a growing interest in Economics regarding the problem of estimating consumers' preferences when they partially ignore the information provided in choice experiments, a problem introduced in this field as attribute non-attendance (Scarpa et al. 2009). This line of research explores the consequences of assuming that consumers use all available attributes to evaluate the alternatives when, in fact, they ignore some attributes. Diverse choice models have been developed to identify non-attendance from choice data. For instance, in latent class models, each segment corresponds to a particular combination of relevant and irrelevant attributes. Due to the combinatorial nature of such an approach, researchers typically explore a limited number of specifications.

In this work, we propose the use of a machine learning approach based on Support Vector Machines to identify the non-attendance of attributes at the individual level and to predict the consumer choices in a conjoint experiment. We conduct an extensive simulation study to investigate the performance of the proposed approach compared to different benchmarks. Our results show a higher performance in terms of the identification of the non-attended attributes that improve the predictive ability of consumers' choices. Finally, we test our approach in two empirical applications previously reported in the literature. We demonstrate the superiority of our approach and the alternative insights derived from our method.

4 - Would you switch? Understanding the potential of intra-peak demand-shifting based on crowdedness discomfort

Katharina Burger, Elisa Becker, Raffaello Rossi

Much hope is placed on novel technologies that provide real-time train crowding alerts to passengers to offer a better journey experience by facilitating a demand shift to less crowded trains. This, in turn, is thought to offer opportunities to optimize operator capacity. However, train commuting behaviour is habitual, and departure-choices are constrained by external factors. As such, there is limited insight into the actual potential for shifting intra-peak departure choices. Our research seeks to identify the relationship between an individual's experienced discomfort with crowdedness, external choice constraints, and information-searching behaviour to understand the intra-peak demand shifting potential. We report the preliminary results from an online experimental study and present the multi-stage design for screening participants to identify regular train-commuters in the UK that travel on highly crowded trains. Finally, we offer a reflection on the opportunities and limitations of the online research methodology for behavioural insights when real-world trials are unfeasible, such as during Covid-19.

■ WB-23

Wednesday, 10:30-12:00 - Virtual Room 23

Advances in Energy Storage and Renewable Generation

Stream: Engineering Optimization
Invited session
Chair: *Majid Eskandarpour*

1 - Approximate dynamic programming for connected hydro reservoirs operation

Farzaneh Pourahmadi, Trine Krogh Boomsma

In this paper, we study the operational problem of connected hydro reservoirs which arises in the context of making sequential decisions in uncertain and dynamic environments. The problem is formulated as a stochastic dynamic program using the Bellman equation and accounting for the uncertainty of energy prices and reservoir inflows without any assumption on their distributions. This stochastic and time-dependent problem suffers from the curse of dimensionality, as the state space explodes with the number of reservoirs and the history of prices and inflows. To avoid computing the expectation of future value functions, the proposed model takes advantage of the post-decision state. To further tackle the dimensionality issue, we propose an approximate dynamic programming method that estimates the future value of water by a linear approximation architecture. A realistic case study serves to demonstrate the computational tractability of the proposed approach. In particular, we provide numerical evidence of convergence and quality of solutions.

2 - Cost-Efficient Control of an Electrical Energy Storage

Michael Stiglmayr

Volatile electrical energy prices are a challenge and an opportunity for small and medium-size companies in energy-intensive industries. By using electrical energy storage and/or an adaptation of production processes companies can significantly profit from time-dependent energy prices and thus reduce their energy costs. We consider the time-discrete optimal control problem to reach a desired final state of the energy storage at a certain time step. Thereby, also the energy input is discrete since only multiples of 100 kWh can be purchased at the EPEX SPOT market. We use available price estimations to minimize the total energy cost by a rounding based dynamic programming approach, by which we yield an approximation of the global optimal solution. With our model we are able handle also non-linear energy loss functions of the storage.

3 - Maximizing the spatial potential of thermal groundwater use by mixed-integer PDE-constrained optimization

Smajil Halilovic, Fabian Böttcher, Thomas Hamacher

Groundwater heat pump systems are one of the key technologies for the energy transition of the heating and cooling sectors. These systems alter the groundwater temperature and cause thermal plumes, which propagate downstream according to the natural groundwater flow. The plumes can reach neighboring systems and deteriorate their efficiency. For this reason, already existing downstream users are legally protected against a severe change of natural groundwater conditions. Hence, it is important to optimally position these systems to avoid negative interactions and simultaneously maximize the spatial potential of thermal groundwater use. Processes that take place in groundwater, i.e. flow and heat transport, are described with a system of nonlinear coupled PDEs. Therefore, the underlying problem is a PDE-constrained optimization problem, which includes control (spatial coordinates of wells) and state (groundwater temperature) constraints. The decision to install a particular groundwater heat pump can be modeled with binary variables. In this talk, we will introduce an adjoint-based approach to solve this mixed-integer PDE-constrained optimization problem. The approach is tested with various numbers of heat pumps and applied to real case scenarios, where the geothermal potential within a city district is maximized.

4 - Simulation-based optimisation for stochastic maintenance routing in an offshore wind farm

Majid Eskandarpour, Chandra Irawan, Dylan Jones, Djamila Ouelhadj

Scheduling maintenance routing for an offshore wind farm is a challenging and complex task. The problem is to find the best routes for the Crew Transfer Vessels to maintain the turbines in order to minimise the total cost. This paper primarily proposes an efficient solution method to solve the deterministic maintenance routing problem in an offshore wind farm. The proposed solution method is based on the Large Neighbourhood Search metaheuristic. The efficiency of the proposed metaheuristic is validated against state of the art algorithms. The results obtained from the computational experiments validate the effectiveness of the proposed method. In addition, as the maintenance activities are affected by uncertain conditions, a simulation-based optimisation algorithm is developed to tackle these uncertainties. This algorithm benefits from the fast computational time and solution quality of the proposed metaheuristic, combined with Monte Carlo simulation. The uncertain factors considered include the travel time for a vessel to visit turbines, the required time to maintain a turbine, and the transfer time for technicians and equipment to a turbine. Moreover, the proposed simulation-based optimisation algorithm is devised to tackle unpredictable broken-down turbines. The performance of this algorithm is evaluated using a case study based on a reference wind farm scenario developed in the EU FP7 LEANWIND project.

■ WB-24

Wednesday, 10:30-12:00 - Virtual Room 24

Linear Programming

Stream: Continuous optimization (contributed)
Contributed session
Chair: *Chinchet Boonmalert*
Chair: *Panthira Jamrunroj*

1 - An Effective Criterion for Selecting a Reinserted Constraint to the Simplex Method based on the Non-acute Constraint Relaxation

Thanaporn Iamsupapong, Aua-aree Boonperm

The simplex method based on the non-acute constraint relaxation (SNAR) is the improved simplex method to solve a linear programming problem without using artificial variables. This method starts by relaxing non-acute constraints called the non-acute constraint relaxation problem (NAR), and it is solved by the simplex method. After the optimal solution or the unboundedness of NAR is found, the non-acute constraints are reinserted to guarantee or search for the solution to the original problem. SNAR is effective when NAR has the optimal solution. However, if NAR is unbounded, then each non-acute constraint is added one by one to NAR without a criterion to choose a non-acute constraint. If the problem consists of many constraints, SNAR will lead to more iterations and more computational time. In this paper, the criterion to choose a non-acute constraint for reinserting to the unbounded NAR is proposed. This criterion can guarantee that if the chosen constraint is added to NAR then NAR is bounded, and its optimal solution can be found using only one iteration. By adding this criterion to SNAR, its computational time can be reduced extremely.

2 - An improved double pivot simplex method by using a circuit direction algorithm

Panthira Jamrunroj, Aua-aree Boonperm

The double pivot simplex method was first proposed by Vitor and Easton in 2018. It was established to improve the simplex method by exchanging basic feasible solutions using two variables instead of one variable. For selecting two entering variables, the slope algorithm is used to identify the optimal basis of the special two-dimensional linear program which has three conditions: both coefficients of objective function are positive, all right-hand-side values are nonnegative and both variables are nonnegative. Although the double pivot simplex method using the slope algorithm can reduce the number of iterations, it has more computation in each iteration. In this paper, we propose the improved double pivot simplex method by using the circuit direction algorithm. This proposed algorithm is also used to solve the special two-dimensional linear program by using a circuit of a feasible region as a direction to identify the optimal basis. It starts at the origin point and a solution is updated by a suitable circuit until the optimal solution is found. Then, it can be also used to exchange two variables into the basis for the simplex method. Since the circuit direction algorithm has less computation than the slope algorithm, it can reduce the computational time to solve the linear program.

3 - The Closed Form of the Optimal Solution to a Blending Problem

Chinchet Boonmalert, Aua-aree Boonperm, Wutiphol Sintunavarat

The blending problem, one of the widespread problems, was first mentioned in 1952. This problem can be formulated to a linear programming model solved by the simplex method which many slack and artificial variables are required. This addition affects the increment of the size of the problem that leads to more computational procedures. In this research, we propose the closed form of the optimal solution to a blending problem provided our conditions. That is, the optimal solution can be obtained rapidly without using any iterative method to find the optimal solution if the problem satisfies our conditions. Moreover, our conditions can particularize if the problem is infeasible.

■ WB-25

Wednesday, 10:30-12:00 - Virtual Room 25

Game Theory and Operations Management 1

Stream: Game Theory and Operations Management
Invited session
Chair: *Behzad Hezarkhani*

1 - Coalition Formation and Cost Sharing for Decentralized Truck Platooning

Yann Bouchery, Behzad Hezarkhani

Truck platooning is a key milestone towards full truck automation. This consists of one or several trucks driving very close behind the platoon leader with the help of technology. Platooning helps to reduce fuel consumption, carbon emissions and congestion while increasing road safety and the productivity of trucks and drivers. In this article, we study the advance planning of platoons as some trucks might be required to wait for optimal platoon formation. We study platoon formation from a system-wide optimization perspective. We provide theoretical results that enable us to solve two special cases in polynomial time. Besides, we provide a method capable of identifying good solutions for the general setting. We posit that truck platooning is much more likely to develop efficiently in decentralized scenarios. This involves a shift in business relation between freight operators through cost sharing. We make use of cooperative game theory and investigate the possibilities of having stable allocations in the core. We show that the core can be empty for instances of the general platooning game. Subsequently, we propose a new allocation rule using intuitive measures to share the costs of platoons among their participating trucks. This allocation rule builds upon a proportional logic which can be easily justified and adopted in the logistics market. Finally, we propose an illustrative example based on the settings of the Port of Rotterdam and provide a series of insights.

2 - Multilateral Pricing in Social Networks under Asymmetric Network Information

Yang Zhang, Ying-Ju Chen

We study multilateral pricing on networks with strategic customers and local consumption externality. The firm cannot observe the number of connections (i.e. degree) that a customer holds in private, and therefore has to price upon global network information (i.e. degree distribution, and the adjacency matrix for degree distribution of neighbors). In multilateral pricing, the firm is able to charge a price based on the joint consumption of neighbors (which resembles the referral program used in practice). While bilateral pricing is the special case where the payment is solely determined by the consumption of one's own. For the classical linear-quadratic customer utility, we establish the closed form solutions for optimal pricing, the induced consumption, and firm's maximum profit as functions of the degree distribution and the neighbor degree distribution matrix. We characterize the conditions when the performance gap between multilateral and bilateral pricing first-order stochastically increases or decreases with respect to the degree distribution.

3 - Supplier Reliability Investment under Incomplete Information

Guven Demirel, Behzad Hezarkhani

We study a game where the buyer outsources the production of an order to a supplier, who is subject to failure risk. The supplier invests to increase her reliability and there are two supplier types that differ in their efficiency of the reliability investment. The buyer offers the purchase price, with or without knowing the supplier type, and can decide to first collect information to update the posterior about the supplier type. Under perfect information, for low supplier efficiency and intermediate reliability, the buyer offers the price that reserves all the payoff for himself, while higher reliability enables sharing the profit between the two parties. If the supplier is highly efficient and the buyer knows this, the buyer offers the lowest price that satisfies the supplier participation constraint where she exerts full effort with no profit. We then solve the problem under imperfect information and establish the conditions under which the inclusive (both types) and exclusive (highly efficient supplier only) contracts dominate. For low supplier efficiency and sufficiently low ratio of the high-over-low reliability ratio, the contract is either exclusive with zero supplier profit or inclusive. We show that for higher reliability ratios, an exclusive contract with profit sharing between the buyer and the high type supplier is possible. Inclusive contracts with both supplier types achieving positive profits dominate when the product value is sufficiently high.

■ WB-26

Wednesday, 10:30-12:00 - Virtual Room 26

Sparse Optimization Theory and Methods

Stream: Nonlinear Optimization
Invited session
Chair: *Yaohua Hu*
Chair: *Fengmin Xu*

1 - Group Sparse Enhanced Indexation Model with Adaptive Beta Value
Fengmin Xu

Enhanced indexing is a portfolio management approach that attempts to increase returns by building a portfolio around core, index-like positions and adding tactical tilts toward specific styles or individual stocks, and has been used by professional portfolio managers for decades. This paper proposes an improved enhanced indexation model by taking into account individual stock's market-related risk, measured by Beta value, and the sector rotation phenomenon which has been observed in economic cycles. In conjunction to minimizing index tracking errors, the proposed model adjusts the portfolio's marketrelated risk in an attempt to maximize the potential gain, by forecasting the future trend of the market. The sector rotation phenomenon shows that various industries and the companies that dominate them thrive or languish as the economy moves in reasonably predictable cycles. To reap the fact, our model aims to find a small set of stock sectors that are mostly likely to thrive in the anticipated future, which is mathematically realized by dividing stocks into sectors and minimizing their L2/1 norm. We conducted extensive numerical experiments against the China A-shares market data. The experimental result shows that our approach can generally achieve sparse tracking portfolios with excellent out of sample excess returns and high robustness.

2 - Trace Lasso Regularization for Adaptive Sparse Canonical Correlation Analysis via Manifold Optimization Approach
Zheng Peng

Canonical correlation analysis (CCA for short) describes the relationship between two sets of variables by finding some linear combinations that maximize the correlation coefficient. However, in high-dimensional settings where the number of variables exceeds sample size, or in the case of that the variables are highly correlated, the traditional CCA is no longer appropriate. In this paper, an adaptive sparse version of CCA (ASCCA for short) is proposed by utilizing the trace Lasso regularization. The proposed ASCCA reduces the instability of the estimator when the covariates are highly correlated, and thus improves its interpretation. The ASCCA is reformulated to an optimization problem on Riemannian manifolds, and a manifold inexact augmented Lagrangian method is proposed for the resulting manifold optimization problem. The performance of the ASCCA is compared with the other sparse CCA techniques in different simulation settings, which illustrates that the ASCCA is feasible and efficient.

3 - Regularization parameter selection for the low rank matrix recovery
Pan Shang, Lingchen Kong

A popular approach to recover low rank matrices is the nuclear norm regularized minimization (NRM) for which the selection of the regularization parameter is inevitable. In this talk, we build up a novel rule to choose the regularization parameter for NRM, with the help of the duality theory. Our result provides a safe set for the regularization parameter when the rank of the solution has an upper bound. Furthermore, we apply this idea to NRM with quadratic and Huber functions, and establish simple formulae for the regularization parameters. To the best of our knowledge, this is the first attempt to select the regularization parameter for the low rank matrix recovery.

4 - Mix Sparse Optimization: Theory and Applications
Yaohua Hu

Inferring gene regulatory networks from gene expression data is an arduous challenge in biology especially in higher organisms, which is found to have a special structure of the transcriptional factory. In this talk, we will consider a mix sparse optimization model with this special structure, that is, sparsity structures at intra-group and inter-group levels are considered simultaneously. We will propose a nonconvex regularization method, as well as a first-order iterative algorithm, and present its consistency theory and convergence theory.

■ WB-27

Wednesday, 10:30-12:00 - Virtual Room 27

Data Science and Analytics - Applications 2

Stream: Data Science and Analytics (contributed)
Contributed session
Chair: *Seunghwan Song*

1 - Contrastive CNN for Mixed-type Pattern Recognition with Single-type Pattern on Wafer Bin Maps
Yunseon Byun, Jun-Geol Baek

Many companies make efforts to classify defect patterns and identify the root causes of defects directly related to the yield in the semiconductor industry. There are some studies for automatic defect classification with single-type patterns of wafer bin maps. Although the classification accuracy has been improved, there are still two limitations. First, it is necessary to classify mixed-type patterns which two or more single-type patterns are mixed. If a mixed-type pattern is missed, all possible root causes cannot be controlled. Second, the model which uses imbalanced and small amounts of labeled data should be proposed. Deep models like convolutional neural network (CNN) require a large amount of labeled data for accurate classification. However, it is hard to obtain the data because defects are very few and engineers give the labels by checking the maps one by one. Therefore, a method with imbalanced and small amounts of data is needed. This paper proposes a contrastive CNN for classifying mixed-type patterns using single-type patterns only. Contrastive learning improves the classification performance and makes the distribution clear for each pattern. Then, we compare the classification probabilities and margin value to determine whether the pattern is mixed or not. WM-811K wafer data was used to verify the proposed model, and the performance was greater than the traditional methods. The model helps improve the overall classification accuracy and control the root causes.

2 - Multitask learning for data-driven wind farm management and condition-based maintenance
Angela Meyer

While wind power is undergoing a strong growth globally, the profit margins of wind farm operators are shrinking in competitive electricity markets. The condition-based maintenance of wind turbines offers a cut in O&M expenses by reducing on-site inspections and unplanned maintenance work. Modern turbines comprise comprehensive sensing technology to enable 24x7 remote condition monitoring. Analyzing this sensor data facilitates the automated detection of incipient faults and asset underperformance. This study introduces multitask machine learning models to enable the monitoring of wind turbine operation and anomaly detection and to support condition-based maintenance decisions by facilitating an early informed planning of inspection and repair. We introduce multi-target machine learning regressions to provide a more efficient and accurate approach for the simultaneous monitoring of wind turbine subsystems. We demonstrate that early faults in the power train can be detected based on component temperatures logged in the turbines' supervisory control and data acquisition systems. We analyze the detection accuracy and detection delays based on multiple machine learning models of the normal turbine operation. Our results demonstrate that multi-target normal operation models can substantially reduce the lifecycle management cost of automated condition monitoring and thus support condition-based maintenance strategies of wind farm owners and operators.

3 - Prediction of Wet Bulb Globe Temperature using Machine Learning

Chang Lu, Yeboon Yun, Min Yoon

In Japan, the number of emergency patients and deaths from heatstroke has been increasing due to abnormal weather as global warming. For preventing heat illness prevention, the Japanese Ministry of the Environment has specified Wet Bulb Globe Temperature (WBGT) as a heat illness risk on the website since 2006. WBGT represents a heat stress index based on the important three factors; temperature, humidity and radiation which effects human heat balance. Depending on environmental situation and condition, WBGT index is calculated from dry bulb temperature, wet bulb temperature and globe temperature. In addition, using generally measured meteorological indices, Ono et al. (2013) suggested the estimation equation of WBGT. In this research, not using meteorological information, we try to predict WBGT index with observed data in the past. Incorporating cycle and autocorrelation of the used data, we propose to construct a WBGT prediction model, and to assess the heat risk ranks -danger, severe warning, warning, caution and almost safe- by machine learning. Then, the proposed method will be applied for predicting WBGT of Osaka, and through the comparison with the conventional method (Ono et al.'s method), which are adopted by the Japanese Ministry of the Environment, the effectiveness of the proposed model is investigated in terms of prediction ability of WBGT index and heat risk assessment using WBGT.

4 - Latent Mapping Adversarial Networks in Manufacturing Defect Synthesis

Seunghwan Song, Jun-Geol Baek

As the end product of the manufacturing process is directly linked to economic factors, various methods are being utilized to improve the quality. Among them, defect detection carried out in advance are important as it greatly impacts productivity. However, new challenges have emerged for several reasons. First, it requires prior knowledge of the expert to define the defect image and perform detection. Secondly, defect detection is an arduous task since fewer defect images are available compared to that of normal images. This underlying problem leads to a classification model that is biased toward the majority class, which degrades the final performance. In this paper, we propose a latent mapping adversarial network. Inspired by StyleGAN, we build mapping networks for latent space of the generator. Through this, we can synthesize defect images of various sizes in the manufacturing process without the prior knowledge of experts. In addition, we experiment to find the most suitable loss function to solve the common problems of generative model. We also optimized the proposed method in terms of the convergence and computation speed by estimating the size of optimal latent space. The experimental results using quantitative metrics illustrate the improved performance of the proposed methodology. As a result, it is now possible to solve the quality problem and increase productivity by reducing misclassification in the model through experiments using the generated images.

■ WB-28

Wednesday, 10:30-12:00 - Virtual Room 28

The Role of Mathematical Optimization in Data Science III

Stream: Mathematical Optimization and Data Science
Invited session
Chair: *Reka Agnes Kovacs*

1 - Learning to Sparsify Travelling Salesman Problem Instances

James Fitzpatrick, Deepak Ajwani, Paula Carroll

In recent years, end-to-end deep learning techniques have been proposed to deal with the high development and running times of exact and approximation algorithms for NP-hard combinatorial optimisation problems. Such techniques, however, are known to have issues of representation, generalisation, complexity, and interpretability. As a compromise, we use machine learning to improve the run time performance of exact algorithms in a matheuristics framework. Leveraging machine learning to develop a pruning heuristic as a pre-processing step followed by an exact integer programming approach, we sparsify instances of the classical travelling salesman problem. We use carefully-selected features derived from cutting planes exploration, minimum spanning tree heuristics and other analysis of the graph edge weights to learn which edges in the underlying graph are unlikely to belong to an optimal solution. We remove these edges, sparsifying the graph, significantly reducing the number of decision variables. Our approach can successfully prune problem instances, removing a large fraction of the variables, even if they lie outside the training distribution, resulting in small optimality gaps between the pruned and original problems in most cases. In the case of metric problem instances, we can also place bounds on the worst-case performance of the sparsifier.

2 - Model and heuristics for the scheduling rich vehicle routing problems after major disasters

Guilherme De Castro Pena, Christian Prins, Andréa Cynthia Santos

Cleaning debris in urban areas after major disasters is very relevant to inhabitants to recover from their effects. In natural disasters, an unexpected and large area can be affected. The time and the costs to perform the cleaning operations can be very high. In this work, the integrated scheduling vehicle routing problem to clean debris (SRP-CD) after major disasters is investigated. The problem includes strategical and operational decisions and, it is motivated by the complexity of the operations. For instance, the synchronization between work-troops and dump trucks is necessary to load, transport and unload debris during limited working days. The goal of SRP-CD is twofold: minimizing the number of days of the overall cleaning, in the strategical level; and minimizing the total costs of vehicles routes in the operational level. A new mathematical model based in a dynamic multi-flow formulation is proposed. In addition, constructive heuristics and a Large Neighborhood Search (LNS)-based metaheuristics are proposed. A data benchmark of interesting instances for SRP-CD from small- to large-size instances is described. Comparison experiments for the model and the approaches are carried out, including extended results using ranking analysis and TTT plots. Results showed that the methods are able to find good quality solutions within a reasonable running time. To the best of our knowledge, these are the first contributions in the literature for SRP-CD.

3 - Binary classification via Ellipsoidal Separation

Benedetto Manca, Antonio Frangioni, Enrico Gorgone

We build upon the general proposal of Grzybowski et al. that defines the concept of separation of two finite point sets X and Y by means of a convex set S. We implement this with S being an ellipsoid. Differently from previous approaches, where the goal was to find an ellipsoid enclosing all points of X and no points of Y, our method aims in finding an ellipsoid which does not contain points of X and Y and which separates them. Since this is in general not possible we mimic the SVM approach by choosing S as having low volume and having the smallest possible intersection with X and Y. The corresponding fitting problem is nonconvex, hence we solve it heuristically via an iterative algorithm of the Gauss-Seidel type alternating an SDP program and a quadratically constrained (convex) one. Using the thusly computed ellipsoid we derive a score for a new point to be classified based on the relative fraction of the original points that are properly separated from it. As a result of the classification paradigm we use, many points (comprised, but not only, these lying inside S) cannot be classified; this puts out approach firmly in the classification with rejection setting, with the benefit that, unlike many other cases, the rejection rule is not "bolted upon" a standard classifier but is really inherent in the way it works. Some preliminary numerical results are presented.

4 - Binary Matrix Factorisation via Column Generation
Reka Agnes Kovacs, Oktay Gunluk, Raphael Hauser

Identifying discrete patterns in binary data is an important dimensionality reduction tool in machine learning and data mining. In this talk, we consider the problem of rank-k binary matrix factorisation (BMF) under Boolean arithmetic: given a binary matrix X of dimension n x m and a fixed positive integer k, find two binary matrices A and B of dimension n x k and k x m such that the discrepancy between X and the Boolean product of A and B is minimum. We describe a novel mixed integer linear programming formulation with exponentially many variables and use column generation technique to solve its LP relaxation. The dual bound provided by our formulation is stronger than the bound given by previously available models for BMF. Experimental results on real world datasets demonstrate that our proposed method is effective at producing highly accurate factorisations.

■ WB-29

Wednesday, 10:30-12:00 - Virtual Room 29

Group Decision Support Systems

Stream: DSS
Invited session
Chair: *Alan Kinene*

1 - An Auction Framework for Assessing the Tendering of Subsidised Routes in Air Transportation
Alan Kinene, Tobias Andersson Granberg, Sebastian Birolini, Nicole Adler

Governments in Europe, United States, Asia, and Australia, through subsidy schemes, offer subsidies along routes that are deemed commercially non-viable but economically and socially essential. These schemes are often criticised due to inefficiencies and excessive subsidies, which result from restrictions defined by transportation authorities during the tendering process, e.g., the maximum airfare and a minimum number of daily flights. We develop an integrated auction framework to provide decision support to transportation authorities when designing tendering processes for subsidised routes. The framework includes two main models. First, the winner determination problem, which the transportation authorities use to select the bids with the minimum subsidies. Second, a novel bid preparation model, which replicates the airline's behaviour when preparing bids for subsidised routes. We capture the responsive relationship between passenger demand and the supply of air services by including passenger utility as an endogenous variable in the bid preparation model. The usefulness of the auction framework is demonstrated with an application to the subsidised routes in Sweden. Our analysis reveals that from the government's perspective of minimising subsidies, having no restriction on both the airfare and the number of flights is the best way to design the tendering process. However, having only a requirement on the maximum airfare is better for the consumers.

2 - Investigation on Collaborative Supply Chain Management Strategies based on the Scales of Business - A study on Sri Lankan Apparel Industries
Sithari Jayamanna, Shirekha Layangani

Deliverance of the right product due in time to the market to an optimum cost drives the apparel manufacturing industry. The practice of managing an agile supply chain (SC) can maintain the right trade-off between cost and supply of customized product to the customer. This practice improves with the capability of collaborating within the SC partners. Despite that, the Sri Lankan apparel industry is a major exporter in the manufacturing sector who has been rewarded over the years for generating a considerable portion of export revenue in Sri Lanka. But 85% of the revenue is generated by a few large-scale players. Rest of the revenue generated by a large portion of small and medium scale apparel companies. It creates a rationale that certain apparel companies are operating at a silo level. It emphasizes the requirement of strengthening the visibility of SC and collaborative strategy. The research paper discusses seven SC collaborative strategies with their attributes that are practising currently. It was a survey-based qualitative study. The participants of the survey were strategic level decision-makers in the apparel SC sector. The content result was analyzed using descriptive analysis and conditional probability. The paper presents a decision support resource which can use to identify applicable collaborative strategy with attributes for industry practitioners.

■ WB-30

Wednesday, 10:30-12:00 - Virtual Room 30

Recent advances in MILP algorithms

Stream: Mixed Integer Linear Programming
Invited session
Chair: *Henri Lefebvre*

1 - Selecting algorithm portfolio for mixed-integer programming without problem instance information
Konstantin Sidorov, Renat Akhunzhanov

Mixed-integer programming is a well-known tool for modeling OR problems. However, the performance of the MIP solver on any given instance can vary depending on the solver settings. One known way to tackle this problem is "algorithm selection", which is selecting a set of algorithms that are likely to perform well on a given MIP instance.

In this paper, we develop an approach for algorithm selection that does not include any information on the problem instance in question. The only source of information is the event log generated by the first iterations of the default SCIP solver, which is represented as a time series and passed into a deep learning model. The key novelty of our approach is its independence from the domain knowledge on the optimization problem - thus, such an approach could be used for developing portfolio selection algorithms for a wide range of OR problem solvers.

We collected performance data and generated event logs for a wide range of publicly available MIP instances. We defined a deep learning model that ranks the algorithms by their predicted performance given the log of events for several first SCIP iterations. The resulting model manages to learn the algorithm selection policy competitive with the previous results. Finally, we present a topological analysis of the problem instance dataset as a time series dataset and show that the instance space (and, in particular, its clusters) is correlated with actual performance metrics.

2 - Combinatorial Benders' cuts
Aigerim Saken

We consider generating Combinatorial Benders' cuts for mixed-integer programs (MIP). Combinatorial Benders' cuts extend the Classical

Benders' decomposition approach by exploiting the polyhedral structure of the problem and making stronger cuts containing a small subset of variables. A combinatorial Benders' cut indicates the need to change at least one of the binary variables appearing in the irreducible infeasible system (IIS) of the subproblem, the cut is stronger than the standard solution elimination constraints, since it makes many more potential solutions infeasible. The main issue with using Benders' combinatorial cuts as a general cut-generating strategy within the Benders' decomposition is that there is no computationally effective algortihm available for isolation of an IIS for mixed-integer subproblems. The literature mostly describes approaches to find an IIS for continuous linear programs. The aim of this research is to address the more general case where the subproblem and the MIP objective function contain both the continuous and the integer variables.This will allow to computationally analyse the merits of the combinatorial cuts.

3 - The Relaxed Nonfeasible-Basis Cutting plane method
Kasitinart Sangngern, Aua-aree Boonperm

In the process of solving the LP relaxation of the cutting plane method, some problems require artificial variables to start the simplex method which leads to more computational time. In this work, we propose the combination of the nonfeasible basis method (NFB) which is the artificial variable free technique, and the relaxing technique to solve the LP relaxation, and the cutting plane method is applied to this relaxed problem. The proposed method is named the relaxed nonfeasible-basis cutting plane method (RNBC). This method starts by relaxing some constraints which do not involve the optimal solution to the LP relaxation problem. Then, the NFB method is applied for solving the relaxed LP relaxation problem (RIP). Next, the cutting plane method is performed to find the integer optimal solution to RIP. After the integer optimal solution to RIP is found, it needs to be checked with the group of relaxed constraints to guarantee that it is the optimal solution to the original problem. From the computational results, the RNBC can reduce the computational time comparing with the traditional method (the artificial technique combined with the cutting plane method) since the RNBC method does not involve the artificial variables and solves the smaller problem.

4 - A finite eps-convergence algorithm for 0-1 mixed-integer convex two-stage robust optimization with objective uncertainty
Henri Lefebvre, Michele Monaci, Enrico Malaguti, Boris Detienne

In this work, we study optimization problems where some coefficients in the objective function are not known at decision time and the decision flow is modeled as a two-stage process. We show that two-stage robust models of this type can be solved by means of a branch-and-price algorithm, in which continuous variables may be selected for branching so as to tighten the optimality gap. The convergence of the method is proven to eps-optimality. Thie proposed approach generalizes a recent result from the literature that could be applied only in the linear case and in presence of linking constraints involving binary variables only. Indeed, our extension allows to address the much wider class of problems with convex constraints and general mixed-integer linking constraints.

From a computational viewpoint, we also propose a generalized diving heuristic that is typically able to compute high quality solutions throughout the execution of the branch-and-price algorithm. We tested our method to two optimization problems: a capital budgeting problem with profit uncertainty, and a variant of the capacitated facility location problem with unknown travel costs and arc-setup costs.

■ WB-31

Wednesday, 10:30-12:00 - Virtual Room 31

Networks, Flows, and Applications

Stream: Network Optimization
Invited session
Chair: *Clemens Thielen*
Chair: *Jan Boeckmann*

1 - On the biobjective shortest path network interdiction problem
Luca Schäfer, Stefan Ruzika

We study a biobjective extension of the shortest path network interdiction problem. Each arc in the network is associated with two integer length values and two players compute their respective shortest paths from source to sink independently of each other while an interdictor tries to lengthen both shortest paths by removing arcs. We show that this problem is intractable and that deciding whether a feasible interdiction strategy is efficient, is NP- complete. We provide a solution procedure to solve the problem on two-terminal series-parallel graphs in pseudopolynomial time.

2 - Multistage stochastic capacity planning in networks
Anthony Downward, Andy Philpott

In this presentation we demonstrate JuDGE, a Julia library for multistage mixed-integer stochastic capacity planning problems. JuDGE provides a framework for formulating complex stochastic programming problems in terms of a tree and nodal subproblems, and solves the problem using a version of Dantzig-Wolfe decomposition.

We present two models built using this framework. The first is a facility location problem with uncertain demand growth, and the second considers electricity network planning (considering both new generation and upgraded transmission lines) in the context of reducing carbon emissions.

3 - Column generation bounds on a network flow model to minimize the total weighted completion time for a single parallel batching machine
Alessandro Druetto, Andrea Grosso

This work deals with the single-machine scheduling problem of minimizing the total weighted completion time in a parallel-batching environment. A very large, graph-based linear programming model is proposed in order to solve a tight relaxation of such problem by means of column generation and dynamic programming techniques. Both a path-based variant and an arc-based variant of the model are developed, in order to obtain two lower bounds of equally good quality. These outclasses the previously known state-of-the-art lower bound. Using the most time efficient of the two variants, the arc-based lower bound, two simple and effective rounding strategies are built, exploiting the information gathered from the relaxation. Combining the strict lower bounds and the effective heuristics allows to generate good feasible solutions with values within a few percentage points from the optimum.

4 - Approximating Network Flow Interdiction with Unit Costs
Jan Boeckmann, Clemens Thielen

In the network flow interdiction problem (NFI), an interdictor aims to remove arcs of total cost at most a given budget from a graph with given arc costs and capacities such that the value of a maximum flow from a source to a sink is minimized. This problem is known to be strongly NP-hard, but - despite its broad applicability - only few polynomial-time approximation algorithms have been found so far.

We present a polynomial-time approximation algorithm for the special case of NFI where all arcs have unit removal costs. To the best of our knowledge, this is the first algorithm for a version of NFI whose approximation ratio only depends on the interdiction budget. On simple graphs, its approximation ratio dominates the previously best known approximation ratio.

■ WB-32

Wednesday, 10:30-12:00 - Virtual Room 32

Urban and Territorial Planning in MCDA 3

Stream: Multiple Criteria Decision Analysis
Invited session
Chair: *Francesca Abastante*

1 - Spatial multicriteria impact assement tools for public and private contexts
Patrizia Lombardi, Sara Torabi Moghadam

The transition towards sustainable and smart cities requires extensive improvement of multidisciplinary performances. However, the design of alternative scenarios is a complex issue which involves a large number of indicators and multiple stakeholders. In this regard, the use of appropriate assessment tools and decision-making models for addressing this issue are needed. This study aims at illustrating the results of two research activities with a specific focus on the definition of policies and decision-making models to guide future transformations in the city, developing a sustainable and smart paths. The first reaserch activity refer an Interreg Europe Programme, which aimed at developing a new city-building approach taking into account the quality of life and energy efficiency. The City of Turin was the pilot case study which intended to develop its low-carbon strategies through the activities of the new City Masterplan. The second project illustrates the development of an ad-hoc interactive impact assessment tool, which is created for innovative Real Estate projects in smart cities. This tool has been applied to a Brazilian demonstrator case-study. The methodology used for delivering both above mentioned tools can be applied to other contexts. The conclusion discusses the similaratiies and differences of the two decision support tools.

2 - Value functions to assess the territorial vulnerability: a multi-stakeholders approach
Catherine Dezio, Marta DellOvo, Alessandra Oppio

According to the National Strategy of Inner Areas (2013), today more than 60% of the Italian territory is occupied by territories, defined as "areas significantly distant from the centres offering essential services, but rich in important environmental and cultural resources and highly diversified by nature" (SNAI, 2013). The current situation of these places is the presence of an abandoned building patrimony and of an underutilized social fixed capital, and a condition of waiting and precariousness for people who decide to stay. The different forms of sustainable tourism can be the appropriate action for a strategy that aims to re-inhabiting Italy starting from the territorial capital. The purpose of the reaserch is to propose a hybrid methodological approach which can support the choice of the building to be recovered for tourism. Both the territorial attractiveness and vulnerability have been assessed and measured supported by a Spatial Multicriteria Decision Analysis (SM-CDA) and within this context, the contribution proposes the phase concerning the generation of value functions developed with a group of experts. A workshop has been organized where experts have been asked to follow a four steps procedure to elicit their opinion about the criteria involved. The study aims at demonstrating the importance of the standardization when multiple and sometimes conflictual criteria are involved in the analysis and the necessity to involve multi-stakeholders competences.

3 - Rating Ecosystemic design actions to plan urban projects
Marta DellOvo, Antonio Longo, Alessandra Oppio

Starting from the Millennium Ecosystem Assessment (MEA) several fields of research have focused the attention on the complex relationship that exists between natural resources, the built environment and the human well-being with reference both to theoretical and operational approaches. Exploring the concept of Ecosystem Services (ESs) by integrating evaluation methodologies with the design process could be strategic in order to support the development of urban projects and to maximize their direct and indirect benefits. ESs could provide multidimensional effects both tangible as the carbon sequestration and climate regulation and intangible as cultural services. Within this context the objective of the current contribution is to propose a rating system for supporting the design phase according to an ecosystemic approach. The evaluation of the design actions has been carried out by interviewing a group of experts which have been asked to assign to each action a score according to the provision of ESs with reference to the hierarchical framework proposed by the MEA. By combining the scores obtained and the importance of each service elicited by the experts, it has been possible to rate the design actions and to propose possible combinations for the development of new urban projects. The rating system can be used to rank, score and compare different projects for their overall performance toward maximizing the ecosystem benefits generated.

■ WB-33

Wednesday, 10:30-12:00 - Virtual Room 33

Complex networks for finance

Stream: New challenges for financial modelling
Invited session
Chair: *Rosanna Grassi*

1 - Clustering coefficients in financial multilayer networks
Rosanna Grassi, Paolo Bartesaghi, Gian Paolo Clemente

Multilayer networks are complex objects encoding many types of relations among nodes. These relations generate different networks at different levels. Each node can be interrelated with nodes on the same level, or with nodes on different levels, including the node itself, and these relations can be described by multilayer networks. Formally, tensors offer an effective mathematical representation for generalizing relations between nodes in multilayer networks. We provide new local clustering coefficients for weighted multilayer undirected networks. We define a local clustering coefficient under different perspectives. Specifically, we introduce four different versions of clustering coefficient: three versions, depending on which nodes and levels are taken into account, and a global one provided for the whole network. This proposal is a generalisation of existing coefficients in the literature. A specific application to financial networks is developed. Through these coefficients we analyse the evolution over time of a financial network, where nodes are assets and weighted links are correlations between assets in a multi-period perspective. Time period evolution is modelled by multiple layers. Since the clustering coefficient is an effective network tool in investigating systemic behaviours in financial networks, the performed analysis shade lights not only on the characteristics of the system at a specific period of time, but also between different time periods.

2 - Robustness assessment for railway network design and investment decisions
Alessandra Cornaro, Daniele Grechi

An efficient railway network is an element of efficiency considering the flow of travelers and goods within a territory. The economic and social aspects, considering also the role of environmental sustainability, are fundamental for the fabric of a region. The focus of this work is the Lombard railway network, the largest in Italy. After having carefully described and analyzed its structure, we detect which nodes and edges are critical, in terms of vulnerability of the network, by means of a suitable robustness indicator. This allows us to determine the portions of the network that need to be upgraded with certain capacity improvement. Moving along these lines, the paper will try to understand, considering the number of circulating passenger trains, what would be the changes in the critical issues considering a reduction or an increase in the number of railway journeys. Moreover, considering the fundamental aspect of the track investment, the work will deal with simulating situation, such as doubling the number of tracks or building new connections between critical edges to verify the effects of these policies, in order to provide a decision support framework that can successfully determine the optimal investment plan. The simulations will also be based on the RFI infrastructure investment plans programmed for the period 2020-2030 to understand if, from a theoretical point of view, these improvements will strengthen and enhance the performance of the Lombardy network.

3 - Modelling spatial insurance risk using complex networks
Gian Paolo Clemente, Francesco Della Corte, Diego Zappa

The assessment of risk related to car crashes in road networks is a relevant topic for both social and political decisions and for insurance companies. With regard to insurance contracts, the presence of telematics devices (as black boxes or in-vehicle data recorders), used in cars and in commercial transport, allow to monitor the driving habits and to collect data crashes. In this field, an open issue is related to the use of this information to quantify the risk of each trip and to assess a specific premium for each policyholder. In this paper we show how the spatial objects and the information concerning the structure of the roads that can be collected from open data sources together with the crash history can be used to map the risk related to each road. In particular, we follow a combined approach. On the one hand, a statistical model will be developed in order to assess the risk on the basis of a set of features related to the characteristics of the streets. On the other hand, from the spatial object we build a weighted network, where vertices and edges correspond to geographical elements as junctions and roads and where the assessed risk of each segment is used as a weight. We study the topology structure of the graph obtained and we show how classical network indicators can provide meaningful insights about the risk of the roads.

4 - Contagion Dynamics between Banks' Customers, Credit Risk and Complex Networks
Anna Grazia Quaranta, Roy Cerqueti, Francesca Pampurini, AnnaGiulia Pezzola

For a bank, understanding the correlation between its customers' transactions is fundamental to improve the credit portfolio quality and, therefore, to contain its credit risk. Indeed, banks must include this element in the evaluation processes adopted, since it can help to maintain a low NPL ratio and to define the more suitable strategies related to the loan pricing, the levels of capital requirements, the composition of credit portfolios and, of course, systemic risk. We propose an approach that shows how the knowledge of the network of relationships and cross-transactions between firms which are customers of the same bank can provide understanding as to whether, and to what extent, the economic-financial difficulties of one of them can produce negative effects on the others due to a contagion effect. We employ a network model in which the nodes represent the customer firms and the links and corresponding weights are defined by the total transaction amounts between them. It is the customers' transaction dynamics that reveal the network structure that connects all the firms, and, starting from it, it is possible to analyse both its resilience and the potential presence of critical nodes. The results of our study can provide an example to show how the proposed approach could be applied, how it can be useful for a bank, how network dynamics can be understood and carefully considered and, therefore, which kind of strategies the bank can play out.

■ WB-34

Wednesday, 10:30-12:00 - Virtual Room 34

(AIRO) Young Researchers in OR

Stream: Combinatorial Optimization
Invited session
Chair: *Martina Fischetti*
Chair: *Lavinia Amorosi*

1 - Benefits of horizontal cooperation for the Share-A-Ride problem
Valentina Morandi, Rossana Cavagnini

Share-a-Ride Problem (SARP) consists in handling people and parcels in an integrated way though the same vehicle, which provides a shared trip between an origin and a destination, in response to requests received in advance. When multiple providers offer ride services within the same city, horizontal cooperation can be an efficient strategy to consolidate all requests and to optimize the total pay-off. In this context, multi-depots must be considered and heterogeneous vehicles may be used. To foster collaboration among providers and maximize the total profit of the coalition, a fair and efficient mathematical programming formulation is proposed.

2 - The Air Transport Unit Consolidation Problem
Lorenzo Peirano, Enrico Angelelli, Claudia Archetti

Consolidation of loose packages into transport units is a fundamental activity oered by logistics service providers. Moving the transport units instead of loose packages is faster (with one movement only, multiple packages are loaded instead of having one load operation for each package), safer (chances of damage and loss is reduced) and cheaper. One of the typical objective of consolidation problems is the minimization of the number of transport unit used, e.g. containers. In air transportation, however, transport units have multiple aspects which concur in the calculation of the cost and thus optimization in the number and characteristics of the transport unit is required. In this paper, we present the air transport unit consolidation problem where the aim is to determine how to consolidate loose packages in transport units with the aim of minimizing the corresponding cost. The problem is a variant of the three-dimensional bin packing problem where the objective function is formulated according to the way costs are calculated in the air transport business. In addition, side constraints are included to take into account specifc requirements. We propose a heuristic algorithm which construct an initial feasible solution and then improves it through a local search algorithm. Computational tests on randomly generated and real data instances show that the algorithm provides high quality solutions in a reasonable computing time.

3 - Routing for unmanned aerial vehicles: touring dimensional sets
Carlos Valverde

In this paper we deal with an extension of the crossing postman problem to design routes that have to visit different shapes of dimensional elements rather than edges. This problem models the design of routes of drones or other vehicles that must visit a number of geographical elements to deliver some good or service and then move directly to the next using straight line displacements. We present two families of mathematical programming formulations. The first one is time-dependent and captures a number of characteristics of real applications at the price of using three indexes variables. The second family of formulations is not time-dependent, instead it uses connectivity properties to ensure the proper definition of routes. We compare them on a testbed of instances with different shapes of elements: second order cone (SOC) representable and polyhedral neighborhoods and polygonal chains. The computational results reported in this paper show that our models are useful and our formulations can solve to optimality medium size instances of sizes similar to other combinatorial problems including neighborhoods that have already been studied in the literature. To address larger instances we also present a heuristic algorithm that runs in two phases: clustering and Variable Neighborhood Search. This algorithm performs very well since it provides promising feasible solutions and, in addition, it can be used to initialize the solvers with initial solutions.

4 - The 0-1 Time-Bomb Knapsack Problem
Alberto Santini, Michele Monaci, Ciara Pike-Burke

We consider a stochastic version of the 0-1 Knapsack Problem in which, in addition to generating profit, each item in the knapsack can explode with a given probability, destroying all the contents of the knapsack. The objective is to maximize the expected profit of the selected items. The resulting 0-1 Time-Bomb Knapsack Problem has applications in logistics and cloud computing scheduling. We introduce a non-linear mathematical formulation of the problem, study its computational complexity, and propose techniques to derive upper and lower bounds using convex optimisation and integer linear programming. We present three exact approaches based on enumeration, branch-and-bound, and dynamic programming, and computationally evaluate their performance on a large set of benchmark instances. The computational analysis shows that the proposed methods outperform the direct application of non-linear solvers and provide high quality solutions in a limited amount of time.

■ WB-35

Wednesday, 10:30-12:00 - Virtual Room 35

Optimization in robotic warehouses I

Stream: Automated Warehouse System
Invited session
Chair: *Lin Xie*

1 - Formulating and solving integrated order batching and routing in multi-depot AGV-assisted mixed-shelves warehouses
Lin Xie

Different retail and e-commerce companies are facing the challenge of assembling large numbers of time-critical picking orders that include both single-line and multi-line orders. To reduce unproductive picker working time as in traditional picker-to-parts warehousing systems, different solutions are proposed in the literature and in practice. For example, in a mixed-shelves storage policy, items of the same stock keeping unit are spread over several shelves in a warehouse; or automated guided vehicles (AGVs) are used to transport the picked items from the storage area to packing stations instead of human pickers. This is the first paper to combine both solutions, creating what we call AGV-assisted mixed-shelves picking systems. We model the new integrated order batching and routing problem in such systems as an extended multi-depot vehicle routing problem with both three-index and two-commodity network flow formulations. Due to the complexity of the integrated problem, we develop a novel variable neighborhood search algorithm to solve the integrated problem more efficiently. We test our methods with different sizes of instances, and conclude that the mixed-shelves storage policy is more suitable than the usual storage policy in AGV-assisted mixed-shelves systems for both single-line and multi-line orders (saving up to 67% on driving distances for AGVs). Our algorithm provides close-to-optimal solutions within an acceptable computational time.

2 - Robotic sorting system: performance estimation and operating policies analysis
Bipan Zou

Many distribution centers use expensive, conveyor-based sorting systems that require large buildings to house them. In areas with tight space, robotic sorting systems offer a new type of solution to sort parcels by destination. Such systems are highly flexible in throughput capacity and are now gradually being introduced, particularly in express companies. This paper studies robotic sorting system with two layouts. The first layout has two tiers, robots drive on the top tier and sort parcels by destination on spiral conveyors connected to roll containers at the lower tier. The second layout has a single tier with input and output points located at the perimeter, connected by robots. For each layout, we consider both the shortest path topology via dual-lane aisles and the detour path topology via single-lane aisles. We build closed queueing networks for performance estimation, design an iterative procedure to investigate robot congestion in the two-tier layout, and use a traffic flow function to estimate robot congestion in the single-tier layout. Random, closest, dedicated, and shortest-queue robot-to-loading-station assignment rules are examined. We validate analytical models by both simulation and a real case of Deppon Express, and analyze the optimal system size and operating policies for throughput capacity and operating cost. The results show that the system throughput capacity is significantly affected by robot congestion in the single-tier layout with the detour path t

3 - Overhead Robotic Compact Storage and Retrieval Systems: Performance Evaluation and System Design
Rong Wang, Peng Yang, Yeming Gong

This paper considers a novel compact storage and retrieval system called the overhead robotic compact storage and retrieval system, which can carry much heavier items to allow more industrial applications, and admit the use of floor space and human-machine interaction. This is the first time that the overhead "robotic" system has been applied to storage and retrieval systems, although overhead traditional (non-robotic) systems have been studied. In this system, bins, as the basic storage and handling containers, are stacked on top of one another to form a bin stack. Bin-picking robots and track-changing robots are used to transport bins between storage/retrieval locations and the workstations along the overhead track to fulfill orders. We establish semi-open queuing network models to sketch the process of the systems based on two track-changing protocols. The accuracy of the analytical models is validated by simulations. The numerical experiments show that the width/length ratio that minimizes the expected throughput time is affected by the storage policy of stacks, and independent of system height. Providing two more robots than the minimum required number can guarantee a low throughput time. If, in the worst case, a sufficient number of robots is not available to meet the demand, the number of workstations can be increased as an alternative. The cost of the use of specialized bin-picking robots can be reduced by 30% with a slight increase in throughput time.

4 - Performance analysis of Multi-tote storage and retrieval autonomous mobile robot system
Zhizhen Qin, Peng Yang, Yeming Gong

The multi-tote storage and retrieval autonomous mobile robot (multi-tote S/R AMR) can carry multiple totes, store and retrieve them from different shelf-rack tiers and transport them to a pick station in a single trip. The special feature of this robot makes it possible to perform order picking applying multi-command cycle pattern. We first analyze the performance of multi-tote S/R AMR system by combining the travel time model and semi-open queueing network (SOQN) methods. Under random sequencing policy and nearest neighbor (NN) sequencing policy, we derive the travel time model for the multi-tote S/R AMR system. Based on the proposed travel time model, we establish a semi-open queueing network to analyze the performance of multi-tote S/R AMR system. The numerical result shows that random sequencing policy performs worse than NN policy under the multi-command operation pattern. Compared with single-tote S/R AMR system, multi-tote S/R AMR system can fulfill the same order task more efficiently with just half the number of robots. The findings reveal that multi-tote robot greatly reduces the required travel time of robot between storage area and workstation. Multi-tote S/R AMR system can do the same job with fewer robots and higher utilization which can improve the throughput performance by nearly 50%. Our research can provide useful guidelines and insights to warehouse managers for configuring and operating multi-tote S/R AMR system.

■ WB-36

Wednesday, 10:30-12:00 - Virtual Room 36

Game Theory, Solutions, and Structures IV

Stream: Game Theory, Solutions and Structures
Invited session
Chair: *Rene van den Brink*

1 - Rawls versus Bentham: a new axiomatic comparison of two classical solutions
Stéphane Gonzalez

The present article provides a new axiomatic characterization of the classical Bentham and Rawls solutions. We define a solution as a mapping which associates to each utility profile a set of outcomes. We combine the standard axioms of nonemptiness, anonymity and unanimity with two different versions of consistency that enable to differentiate the Bentham solution from the Rawls solution. Both axioms of consistency can be interpreted as axioms of decision-making in groups under uncertainty.

2 - A characterization of the core for totally positive games without any consistency axiom
Sylvain Béal

The core is one of the most well-known solution concepts for cooperative (TU) games and has been extensively axiomatically characterized. So far, all these characterizations invoke a consistent axiom. In this article, we provide the first characterization of the core without any consistency axiom. The price is that we restrict the domain under consideration to totally positive games, i.e. games with non-negative Harsanyi dividends. Many applications of cooperative games give rise to totally positive games. Two important aspects of our characterization are that (i) the core is an additive solution concept on the class of totally positive games and (ii) we rely on a new fairness axiom: if two players are equal and if an allocation in the solution set assigns a greater payoff to one of them, then any allocation obtained by a transfer of at most this payoff difference from the richer to the poorer equal player should belong to the solution set as well.

3 - Essential coalitions in unbalanced games
Miklós Pintér, Zsófia Dornai

Huberman (1980) defined the class of essential coalitions for balanced games. These essential coalitions form a characterization class of the (pre)nucleolus (Schmeidler, 1969) in balanced games.

We introduce two new notions t_1-essential coalitions and first order essential coalitions, both of which form a characterization set of the prenucleolus for any TU-games.

4 - Valuation Monotonicity, Fairness and Stability in Assignment Problems
Rene van den Brink, Marina Nunez, Francisco Robles

In two-sided assignment markets with transferable utility, we first introduce two weak monotonicity properties that are compatible with stability. We show that for a fixed population, the sellers-optimal (respectively the buyers-optimal) stable rules are the only stable rules that satisfy object-valuation antimonotonicity (respectively buyer-valuation monotonicity). Essential in these properties is that, after a change in valuations, monotonicity is required only for buyers that stay matched with the same seller.

Using Owen's derived consistency, the two optimal rules are characterized among all allocation rules for two-sided assignment markets with a variable population, without explicitly requiring stability.

Whereas these two monotonicity properties suggest an asymmetric treatment of the two sides of the market, valuation fairness axioms require a more balanced effect on the payoffs of buyers and sellers when the valuation of buyers for the objects owned by the sellers change. For assignment markets with a variable population, we introduce grand valuation fairness requiring that, if all valuations decrease in the same amount, as long as all optimal matchings still remain optimal, this leads to equal changes in the payoff of all agents. We show that the fair division rules are the only rules that satisfy this grand valuation fairness and a weak derived consistency property.

■ WB-38

Wednesday, 10:30-12:00 - Virtual Room 38

Equitable and sustainable Covid-19 vaccine distribution

Stream: Humanitarian Operations
Invited session
Chair: *Burcu Balcik*
Chair: *Hossein Baharmand*

1 - Covid-19 Vaccine Scheduling Considering Thermal Shipping Containers
Elvin Coban

Due to the Covid-19 pandemics, more than 1.6 million people died and more than 76 million people got sick in 2020. Vaccine candidates tested for COVID-19 in humans in June 2020 were found to trigger immunity without any severe side effects. Hence, almost all countries adopt vaccination at an increasing pace. However, there are different types of vaccines and some require ultra-cold chain storage. We study the scheduling problem of Pfizer-Biontech vaccines via a mixed-integer linear programming model with the cold chain requirements. Especially, we consider the thermal shipping containers assuming that not all healthcare centers can afford and/or prefer buying/renting special freezers. We also perform preliminary analysis on the required capacities to finish vaccination before a predefined deadline.

2 - An Equitable Vaccine Allocation Problem
Berna Akça, Ecem Yücesoy, Sırma Karakaya, Asena Ayse Gevsek, Burcu Balcik

The world's struggle with the Covid-19 pandemic has been going on for more than a year. The countries face significant challenges to employ the available vaccines effectively. We address a vaccine allocation problem, in which a scarce amount of vaccines must be equitably allocated among different priority groups and geographical areas in a country. We present different allocation policies and a case study to compare the performance of each policy. This study is supported by the CONTRA project, which is funded by the Research Council of Norway.

3 - A model for COVID-19 Vaccine Allocations: A Case Study in Australia
Naima Saeed, Babak Abbasi, Masih Fadaki, Olga Kokshagina, Prem Chhetri

The objective of this paper is to develop a mathematical model to analyze the COVID-19 pandemic vaccine allocation decisions. We have considered the factors including susceptibility, exposure and operational constraints. The conceptual model integrates a centralized booking system, risk profiling and prioritization, and a vaccine distribution system to develop an effective vaccine allocation model. We have considered the possibility of transshipment between medical centers and varied vaccine package sizes. The case study is focused on Victoria, Australia and the proposed model has been applied to different scenarios of vaccine allocation and distribution. To enhance logistical capabilities, this research recommends specific guideline for COVID-19 vaccine distribution for policy makers and other stakeholders.

■ WB-41

Wednesday, 10:30-12:00 - Virtual Room 41

Inventory management

Stream: Production and logistics and revenue management (contributed)
Contributed session
Chair: *Tal Avinadav*

1 - Optimal replenishment policy for an inventory system with time-dependent demand and partial backlogging
David Alcaide Lopez de Pablo, Luis A. San-José-Nieto, Valentín Pando-Fernández, Joaquin Sicilia-Rodriguez

This work analyzes an inventory system with time-dependent demand and partial backlogging. Demand follows a power pattern and a fixed fraction of this requested quantity in the shortage period is backlogged. Unlike to consider as objective the minimum cost or the maximum profit per unit time, which are more common in the literature on stock control, the aim consists to maximize the return on inventory expense, which can be an appropriate criterion for inventory system managers. Depending on the input values of parameters, various different situations are analyzed. The optimal scheduling periods, the initial inventory levels and the optimal lot sizes are derived for all those situations. Also, when a constant demand is considered, the optimal inventory policy is explicitly determined. It is shown that the optimal policy obtained with the criterion of maximizing the return on inventory expense is, in general, different from that which maximizes the profit per unit time. Moreover, several numerical examples are presented to illustrate how the optimal approach developed in this article works.

2 - Decentralized Inventory Planning with Transhipments in a Multi-Project Environment
Secil Savasaneril, İsmail Serdar Bakal, Duygu Soylu Nazlı

Many companies in project-based industries manage their inventories in a decentralized manner on a project-by-project basis. Multiple projects may use common components, and decentralized planning may result in excess demand of the component in one project and excess supply in the other. Costs due to such mismatches can be decreased with transfer of components between projects. Designing a transhipment mechanism might be challenging if uncertainty exists in both project start-times and component requirements. We investigate the ordering decisions of two different purchasing agents, who make inventory planning for two different projects. The projects may use different amounts of the component, and may have different start times, which affect the arrival time of the component. We study a transhipment mechanism where the project with excess inventory transfers the excess amount at a transfer price. The purchasing agents get engaged in a quantity ordering game. We prove the existence and uniqueness of the equilibrium quantities and characterize the equilibrium. Through the numerical analysis, we find that purchasing agents may achieve significantly higher profit under transhipment than under no transhipment. The benefit of transhipment increases when order quantities tend to be low and decreases if the order arrival times of the components differ across projects. Finally, there may not exist a coordinating transfer price due to the uncertainty in project start times.

3 - EOQ-based analysis of advanced supply disruptions information
Georgios Karakatsoulis, Konstantina Skouri, Athanasios Lagodimos

Consideration is given to the impact of advanced supply disruptions information (ASDI) on the performance of a simple inventory system. This comprises of a single echelon installation, facing a fixed-rate deterministic demand which, when unsatisfied, is backordered. While a fixed-delivery schedule is agreed, the supplier is unreliable so deliveries may fail, following a Bernoulli process. The objective is to determine the schedule that minimizes average cost. Assuming no information on supply disruptions, an exact solution that corresponds to the optimal setting of a base stock policy exists. To study advanced disruption information, we modify the original problem assumption as follows: while the pattern of supply disruptions remains random, after any delivery, the supplier can now specify exactly the timing of next delivery, offering the opportunity to order as necessary to cover this known interval. Invoking the concept of myopic policies, the respective cost reduces to the weighted average of deterministic base stock policies (each with different periods) and determine the optimal solution; interestingly, an EOQ type expression for the optimal inter-delivery time prevails. Analytical properties presented and numerical results strongly highlight the value of advanced information in reducing supply disruption costs, becoming particularly as supply quality deteriorates. We use analysis of the ASDI model to better understand the safety stocks needed in situations without ASDI.

4 - The role of leadership in a supply chain of perishable product
Yael Lahav, Tal Avinadav, Tatyana Chernonog

The question of how leadership affects of a perishable product's supply chain is investigated in this paper. The main findings are: (i) for a given cycle length, the selling price,thus the total profit of the channel are not affected by the identity of the leader; (ii) the selling price encompasses a narrow band; (iii) for each party, being a leader is more profitable than being a follower; (iv) consumers enjoy a fresher product when the retailer is the leader. Moreover, it is observed that when the cycle length is determined in a cooperative manner, the total profit of the channel is slightly higher when the retailer is the leader as opposed to the manufacturer.

■ WB-42

Wednesday, 10:30-12:00 - Virtual Room 42

Banking risk Management II

Stream: Enterprise risk management
Invited session
Chair: *David Christen*

1 - Manufacturer Credit Financing vs Platform Credit Financing: An Analysis of 3-Echelon Online Supply Chain
Sambit Brata Rath, Preetam Basu, Prasenjit Mandal

Third-party sellers are an integral part of e-commerce marketplaces. Many of them are small and Medium Businesses (SMBs). Therefore, they are always in need of working capital to finance their day-to-day operation. Recently, many of these platforms have started novel financing programmes (platform credit financing, PCF) for the sellers. For example, Amazon provides unsecured loans to third-party sellers on its platform under the Amazon lending program. In this paper, we are comparing upstream financing mode with downstream financing mode in a 3-echelon online supply chain. The monopolistic retailer, who is selling a single product on a platform, is capital constrained. It has two financing modes; one is manufacturer credit financing (upstream financing) and the other one is platform credit financing (downstream financing). Our analysis shows that for lower values of referral fee rate, the retailer and the manufacturer will prefer upstream financing whereas the platform will prefer downstream financing. When the referral fee rate will be very high, everyone will prefer downstream financing. We also design some contracts to coordinate the supply chain. We also explore the case, where the retailer has some supply chain risk associated with it. We found that the nature of the result remains the same. Only the threshold values reduce with an increase in the risk. When the risk becomes very high downstream financing dominates the upstream financing always.

2 - Do late payers decide to pay faster? The role of firm size in the persistence of late payment
Michel Dietsch

Despite laws implementing a 60 days' norm in payment terms, late payments stay as a subject of concern. In this paper, we investigate whether late payers, i.e. firms with payables exceeding 60 Days' Purchases Outstanding (DPO), subsequently reduce their payment delays. Using the accounting data of a large database of French firms provided by the Banque de France and covering the 2004-2017 period, this paper investigates the payment behavior of late buyers by measuring the change of payables delays firms which are late payers decide to implement from one year. After controlling for firms' operational and financial characteristics, results show that late payers reduce their DPOs by 5.1 days on average. However, this number systematically varies across firm size. While SMEs paying late reduce significantly their DPOs, returning cash to their suppliers, large firms make on average no effort, keeping cash in their cash reserves. Thus, the removal of late payment are more the result of small buyers than large and it induces significant transfers of cash between firms of different size. Our results are consistent with the supply chain finance literature hypothesis that larger buyers use their bargaining power either to raise or to keep permanently the liquidity provided by their suppliers. Michel DIETSCH, Université de Strasbourg, LARGE Olivier GONZALEZ, Observatoire des Entreprises, Banque de France Joël PETEY, Université de Strasbourg, LARGE

3 - The Impact of Three Financial Crises on Banks Efficiency. A Euro Area Banking System Analysis
Francesca Pampurini, Anna Grazia Quaranta

The issue of bank efficiency and, more generally, of the whole banking system efficiency is a topic that has deep origins in scientific literature. The aim of our contribution is to analyse the impact of the three recent financial crises on the level of banks efficiency to discover its determinants and, therefore, to suggest some managerial and policy operational implications. We analysed the banking groups in the main Euro Area countries in a specific period (2009-2019) characterised by strong turbulence in the financial markets and by a large number of economic difficulties. Therefore, it is highly emblematic of the complexity of the banking and financial markets in the last decade. We obtained the banking groups' efficiency levels via a DEA model based on inputs and outputs proxies deriving from the well-known and most used intermediation approach. The results show that the main determinants of a high level of efficiency are linked to a particular business model concerning traditional lending activities, to specific managerial decisions, such as the achievement of a medium-size along with a rational valuation of the number of firms that are part of the same banking group and to suitable cost rationalisation strategies and liquidity reserve optimisation policies.

4 - A Moments-Based Approach to Imperfect Granularity in Exchangeable Credit Risk Models
David Christen

We introduce a novel algorithm that allows the computation of moments of weighted averages of exchangeable random variables and apply the algorithm to the problem of imperfectly granular portfolios (i.e., there is only a finite number of positions in the portfolio, and some positions may have larger weights than others). We characterize the distributions of imperfectly granular portfolios by finding a potentially suitable type of distribution from the (analytically tractable) case with perfect granularity, and by then parameterizing the distribution with the help of the moment algorithm. A numerical analysis identifies conditions under which this approach works well.

■ WB-43

Wednesday, 10:30-12:00 - Virtual Room 43

Sports scheduling

Stream: OR in Sports
Invited session
Chair: *Xiajie Yi*

1 - Multi-league sports scheduling problems with different leagues sizes
Miao Li, Dries Goossens, Morteza Davari

In amateur sports, sports associations may have hundreds of leagues which cannot be scheduled independently from each other. In these leagues, clubs typically have several teams (e.g., based on age or skill of players). All teams from the same club share the same infrastructure. This causes a capacity problem at each club: clubs can host at most a number of matches equal to their number of venues. Against this background, we investigate the simultaneous scheduling of multiple sport leagues with different leagues sizes during a planning horizon consists of a number of rounds. The goal of the problem is to determine the assignment of home-away patterns (HAP) to teams for each league and the starting round of each league to minimize the summation of capacity violations over all clubs and all rounds. We formulate this problem as a mixed integer programming (MIP) model and design a tailored heuristic to find solutions for this problem. To evaluate the heuristic, we generate a set of instances inspired by a real-life case. Our heuristic outperforms the MIP model in the majority of these instances, especially when the problem scale is large.

2 - Decomposition approaches for time-relaxed scheduling: optimizing rest times and differences in games played
David Van Bulck, Dries Goossens

Time-relaxed sports timetables utilize more time slots than there are games per team and are therefore suitable to take into account availability of teams and sports infrastructure. However, in time-relaxed timetables the rest period between teams' consecutive games can vary considerably and the difference in the number of games played by any two teams can become large. A popular technique to construct time-constrained sports timetables is the first-break-then-schedule approach, which first determines for each time slot whether a team plays at home or away (the so-called home-away pattern, HAP) after which its opponent is determined. Can we use a similar decomposition approach to construct time-relaxed sports timetables that are less prone to the aforementioned issues? Observing that rest times and differences in games played are fully determined once the game days and the off days (also called byes) of each team are fixed, we propose to first determine so-called game-off-day patterns (GOPs) after which we construct a compatible timetable that specifies the opponents and the home advantage of the games. It turns out that deciding whether or not a compatible timetable exists for a given HAP or GOP set is an NP-complete problem. Computational results show that our approach outperforms existing approaches to optimize rest times and differences in games played when the total number of off days is no more than twice the number of games per team.

3 - Social Golfer Problem - Fairness in the Volleyball Nations League
Roel Lambers, Laurent Rothuizen, Frits Spieksma

The Volleyball Nations League is the elite annual international competition within volleyball, with the sixteen best nations per gender contesting the trophy in a tournament that spans over 6 weeks. The first five weeks contain a single round robin tournament, where matches are played in different venues across the globe. As a result of this setup, there is a large discrepancy between the travel burdens of opposing teams, leading to a disadvantage for the teams that have to travel a lot. With the aim of minimizing this unfairness, we analyze the problem as a variant of the Social Golfer Problem. The resulting problem can be conveniently decomposed into two parts, where solving the problem with respect to fairness equals solving the so-called Venue Assignment Problem. Instances of this problem can be formulated as an Integer Program, and for real-life instances we find the fairest schedules with respect to the difference in travel times. In addition, it turns out that the fairest schedules don't significantly increase the total travel time of the teams.

4 - Developing sports schedules with maximized suspense using an implementor/adversary approach
Xiajie Yi, Dries Goossens, Jeroen Belien

Suspense is one of the key elements to make a sports competition interesting to watch and enjoy. Ideally, a sports schedule keeps the suspense of the tournament in spite of various possible game outcomes. In round-robin competitions where each team plays against each other team same number of times, the suspense of the tournament can be measured by how late in the season the winner is decided, namely, the title round. Aiming at having the title round as late as possible in the tournament, we develop an implementor/adversary approach that gives guarantees with respect to the worst-case title round for a set of realistic scenarios. Each scenario consists of an outcome for each game in the season. Thus, different scenarios have various probabilities. The implementor problem aims at designing the most suspenseful schedule with a given set of scenarios, while the adversary problem searches for a new scenario which can break the suspense of the obtained schedule. Our approach also allows to make a trade-off between the extent to which unlikely scenarios are considered and the quality of the timetable obtained in terms of suspense. We conclude with applying our approach to schedule the play-offs in Belgian professional football.

■ WB-44

Wednesday, 10:30-12:00 - Virtual Room 44

Fast and furious: lightning talks

Stream: Practice of OR (Making an Impact)
Invited session
Chair: *Ruth Kaufman*

1 - Lightning talks

Ruth Kaufman

When a conference has 2000 papers in the book of abstracts, and maybe 40 or more sessions at any one time, how do you choose which to go to? And how do you avoid being frustrated by only being able to see a tiny fraction of what is on offer?

This session aims to boost the odds in your favour, by bringing together 10 of so speakers whose talks are of potential interest to practitioners, and inviting them to compress their talk into a lightning 5-minute presentation. With a couple of breaks for discussion, this is a high-intensity, high-energy session which will showcase contributed abstracts across a wide range of OR methodologies and application areas.

'Fast and furious' lightning talks has been a highly-successful session at previous EURO conferences and we are sure that this year's will be as stimulating and enjoyable as ever.

The full list of papers and speakers will be finalised shortly before the conference starts, and will be available via the 'Making an Impact' webpages here: https://euro2021athens.com/specific-sessions/

■ WB-45

Wednesday, 10:30-12:00 - Virtual Room 45

Online and Omnichannel Retailing I

Stream: Demand and Supply in Consumer Goods and Retail
Invited session
Chair: *Tom van Woensel*
Chair: *Danny Segev*

1 - Efficient decentralised supply chains for optimal service levels: Simulating, optimizing, and benchmarking supply chains for retailers

Matthew Bayani, Tiru Arthanari, Timofey Shalpegin

Traditional retailers find it challenging to keep up with online retailers on price, delivery times, and product range. In the recipe of traditional retailing, a crucial element is reducing the costs of operations, which are immediately visible. Loss of sales is rarely discussed in the literature, since it can be difficult to observe in the short-term, and is typically indirect. Due to modeling limitations, existing facility location techniques tend to focus on continuous models without taking into account throughput. An example from New Zealand illustrates realistic constraints that can be applied anywhere. We present a framework for exploring and benchmarking different distribution network designs for the retail sector. A large proportion of multichannel box retailers are centralised, but the trend is moving towards decentralisation. We have no way of assessing how various supply chains behave. As such, decisions, like opening warehouses or converting stores to Click-and-Collect, or adding fulfillment centers to existing stores, have an adverse effect on lead times due to demand volatility. We compare the distribution network performance in two illustrative scenarios using a two-stage approach, including linear programming and a discrete-event simulation under stochasticity. The results suggest that decentralisation increases retailer profits, lowers inventory costs, and vice versa. This framework will help decision-makers design for better supply chain performance.

2 - A two-stage optimization framework for scheduled E-grocery delivery

Siddhartha Paul, Goda Doreswamy

The E-grocery delivery business is experiencing unprecedented growth owing to the current COVID pandemic situation. The trend is expected to remain the same, even after the situation is normal. The success of E-grocery depends on the cost-effectiveness and timely delivery of orders. This paper proposed a two-stage optimization framework for the scheduled E-grocery delivery-cost minimization. In the first stage, Last-Mile (LM) delivery optimization is modelled as a Pickup and Delivery Problem with Time Windows (PDPTW). This PDPTW problem is solved using a two-phase method comprising a construction heuristic (savings method) and a meta-heuristic (guided local search). The first stage returns a set of routes that optimizes the LM. The second stage solves the First-Mile delivery optimization problem using a multi-objective assignment model for assigning nearby Delivery Executives (DE) to the first stage's routes. Various practical business constraints, like DE bag volume, maximum weight, etc., are also considered. Sensitivity analyses are performed on the model parameters and found bag volume as a critical parameter for minimizing the cost. Two policies viz. overlapping slot (delivery slot are overlapping) and non-overlapping slot are compared. The overlapping slot is found to provide a relatively lower cost. This model is implemented in two Indian cities, exhibiting promising results (efficient delivery, cost-saving, giving another business case to invest in instant delivery).

■ WB-46

Wednesday, 10:30-12:00 - Virtual Room 46

Revenue Management and Pricing

Stream: Revenue Management and Pricing
Invited session
Chair: *Catherine Cleophas*

1 - Detecting outlying demand in multi-leg bookings for transportation networks

Nicola Rennie, Catherine Cleophas, Adam Sykulski, Florian Dost

Network effects complicate transport demand forecasting in general and outlier detection in particular. For example, a sudden increase in demand for a specific destination will not only affect the legs arriving at that destination, but also connected legs nearby in the network. Network effects are particularly strong when service providers, such as railway or coach companies, offer many multi-leg itineraries. In such situations, automated alerts can help analysts to adjust demand forecasts and enable reliable planning.

In this presentation, we outline a novel two-step method for automatically detecting outlying demand from transportation network bookings. The first step clusters network legs according to the observed booking patterns. The second step identifies outliers within each cluster to create a ranked alert list of affected legs. We illustrate the method using empirical data obtained from Deutsche Bahn. In addition, we present a detailed simulation study that quantifies the improvement from the clustering step and implications of ranking to measure the criticality of the outliers. Our results show that the proposed approach outperforms independently analysing each leg, especially in highly connected networks where most passengers book multi-leg itineraries.

2 - Dynamic Pricing and Inventory Management of a Dual-channel Supply Chain under Different Power Structures
Mengmeng Li, Shinji Mizuno

This paper studies a periodic review, joint dynamic pricing and inventory problem for a dual-channel supply chain with one manufacturer and one retailer, where the demand is stochastic and price sensitive. Three possible power structures between manufacturer and retailer in the dual-channel supply chain, i.e., Manufacturer Stackelberg, Retailer Stackelberg and Vertical Nash, are considered. Under each of the three power structures, decision models are developed with stochastic dynamic programming to determine how to adjust the pricing and inventory decisions in every period so that each member's total expected discounted profit over the planning horizon is maximized. The effects of the power structure are analyzed by comparing the optimal dynamic pricing and inventory policies under different power structures. Results show that: (i) the optimal dynamic pricing and inventory policy of a dual-channel supply chain is an inventory-dependent base-stock-list-price policy; (ii) list prices are independent of starting inventory levels, while base stock levels and reduced prices are affected by starting inventory levels; (iii) the influence rules on reduced prices under different power structures are the same, while the influence rules on base stock levels vary according to the power structure; (iv) optimal pricing and inventory decisions are affected by the power structure, although the structural properties of the optimal policy under different power structures are the same.

■ WB-47

Wednesday, 10:30-12:00 - Virtual Room 47

MINLP Algorithms and Machine Learning

Stream: Mixed-Integer Nonlinear Optimization
Invited session
Chair: *Ivo Nowak*

1 - On Global Optimization aspects of learning
Eligius M.T. Hendrix

(Machine) Learning of predictive and classification models has been considered by many researchers as Mixed Integer Nonlinear Optimization problems. Traditional gradient base methods implemented in learning algorithms may suffer from effective convergence leading to researchers going for evolutionary algorithms. We will focus on the characterization of the underlying optimization landscape and pose some questions on the effectiveness of algorithms given the optimization challenges.

Our point of view looks at parameter estimation, ill conditioning, parameter identification and symmetry leading to infinitely many parametrizations providing similar performance. The latter is related to what is called over-parametrization in deep learning. Gradient based methods suffer from ill-conditioning and vanishing gradients in the network. On the other hand, evolutionary type algorithms just hop around in high dimensional spaces without any guarantee to converge to a predictive model (parametrization) with a good performance. We will use several small instances to showcase the underlying difficulties. This research has been supported by the Spanish state project RTI2018-095993-B-I00

2 - Decogo - A software framework for modular optimization
Ivo Nowak, Pavlo Muts, Eligius M.T. Hendrix, Ouyang Wu

In this talk we present Decogo, a recently developed software framework for solving complex modular optimization problems. The advantages of the new solver are: (i) no global branch-and-bound tree is used, (ii) sub-problems can be solved in parallel to generate columns, which do not have to be optimal, (iii) an arbitrary solver can be used to generate solutions of sub-models, (iv) a set of high-quality solutions, which can be inspected by the user, is generated. We show numerical results for large scale MINLP models, and discuss improvements and possible applications in engineering and machine learning.

3 - Dynamic column generation: a new approach for refining inner approximations of MINLPs
Ouyang Wu, Pavlo Muts, Ivo Nowak, Eligius M.T. Hendrix

This work attempts to extend inner approximation approaches for solving large-scale mixed-integer nonlinear programming (MINLP) problems. We consider general nonconvex MINLP problems that can be reformulated or decomposed into block-separable MINLPs, defined by linking low-dimensional sub-problems (called atomic blocks) with linear coupling constraints. With a block-separable structure, column generation (CG) can efficiently generate feasible solutions of sub-problems, defining as columns for a master problem; therefore, it provides inner approximations to convex relaxation of MINLPs, which is used by primal heuristics to compute solution candidates. Dynamic generation of hyper-blocks is proposed to reduce a duality gap of the original MINLP in the CG approach. These hyper-blocks adaptively combine atomic blocks of the block-separable structured MINLP and generate cuts to the convex relaxation of MINLPs. This helps to generate tighter convex relaxation of the MINLPs, and therefore reduces the duality gap and improves the primal heuristics. For numerical validations, we perform experiments on MINLP instances.

■ WB-48

Wednesday, 10:30-12:00 - Virtual Room 48

Emerging Aspects of Electric Transportation

Stream: Emerging technical and financial aspects of energy problems
Invited session
Chair: *Miguel F. Anjos*

1 - Designing hydrogen production and distribution infrastructure for zero-emission maritime transportation under uncertain demand
Šárka Štádlerová, Peter Schütz, Asgeir Tomasgard

Decreasing CO2 emissions from maritime transport is an important step to meet the requirements of the Paris agreement. Hydrogen is considered as a way to decarbonize the maritime sector, but the infrastructure for producing and distributing hydrogen must be designed to ensure the supply.

We study the problem of where to locate hydrogen plants, which production technology to choose, and how much capacity to install to satisfy future customer demand. Customer demand is expected to increase over the next years but is also the main source of uncertainty. The objective is to minimize total expected costs consisting of general facility costs and linear distribution costs. Facility costs are subject to economies of scale and are therefore non-linear. They cover both investment costs, and production costs. We formulate the facility location and capacity expansion problem as a multi-stage stochastic programming model. The first stage decisions cover decisions regarding location, capacity, and technology as well as production and distribution plan for deterministic demand. The second stage decisions relate to capacity expansion and hydrogen production and distribution while the decisions in the third stage relate only to production and distribution.

We apply our model to a case from Norway, designing the Hydrogen supply chain for coastal maritime transportation and passenger ferries.

2 - Strategic placement of electric vehicle charging stations based on geographically resolved driving patterns and energy system related factors
Marcel Dumeier, Jutta Geldermann

A rising number of electric vehicles and the charging of these vehicles is projected to have an impact on the overall electricity demand. More specifically, the placement and capacity of charging stations influences when charging can be conducted, resulting in different electricity demand curves. The placement of the charging infrastructure may therefore have several effects regarding e.g. utilization of the stations or the overall electricity demand patterns. A linear optimization model for location planning is implemented to coordinate both the expansion of the charging infrastructure and charging of vehicles for different electricity system configurations and degrees of vehicle diffusion. The model is applied to a case study for the expansion of the charging infrastructure in a German city with about 500.000 inhabitants. Combining geographic information systems (GIS) and optimization models enables the investigation and evaluation of different charging infrastructure configurations on energy system related factors, e.g. the occurrence of local grid surges or the efficient utilization of volatile electricity supply. Thus, the presented model allows to support decisions on the optimal placement of the charging infrastructure on multiple levels and on expansion strategies for several years.

3 - Optimal Incentive in Electric Vehicle Adoption
Giorgio Rizzini, Paolo Falbo, Cristian Pelizzari

In this paper, we investigate through a bilevel model the interactions between a policymaker and a population of vehicle owners. The policymaker aims at minimizing a cost function deciding the optimal incentive to encourage the largest possible percentage of the fossil-fueled vehicle owners to purchase an electric vehicle. Fossil-fueled vehicle owners have to decide about purchasing or not an electric vehicle. Both policymaker and fossil-fueled vehicle owners care about PM_{10} concentration. In particular the policymaker can decide to impose a traffic ban if the PM_{10} concentration exceed the safety threshold for many consecutive days. These stops generate a cost to the owners of a fossil-fueled vehicle. We reduce the initial bilevel formulation to a single level problem and then we solve it analytically. We provide a model calibration through real data and a detailed comparative statics.

■ WB-49

Wednesday, 10:30-12:00 - Virtual Room 49

Multidimensional Queues

Stream: Performance Evaluation of Queues
Invited session
Chair: *Tuan Phung-Duc*

1 - Continuity problem for singular BSDE with random terminal time
Sharoy Samuel, Alexandre Popier, Devin Sezer

We study a class of BSDE with a superlinear driver adapted to a filtration F and over a random time interval [0, S] where S is a stopping time of F. The terminal condition xi is allowed to take the value infty, i.e., singular. Our goal is to show the existence of solutions to the BSDE in this setting. We do so by proving that the minimal supersolution to the BSDE is a solution, i.e., attains the terminal values with probability 1. We consider three types of terminal values: 1) Markovian 2) xi1 = infty . 1 tau ≤S and 3) xi2 = infty .1 tau >S where tau is another stopping time. We call S solvable with respect to a given BSDE and filtration if the BSDE has a minimal supersolution with terminal value infty at S. Solvability plays a key role in many of the arguments. Finally, we discuss the implications of our results to the solution of nonlinear elliptic PDE with singular boundary conditions.

2 - M/G/1 Ticket Queue with Balking Customers
Moeko Yajima, Ayana Kurumazuka, Naoto Miyoshi

A ticket queue is a mathematical model to represent systems such that customers are managed with numbered tickets (e.g. pharmacies, post offices and government offices). In a ticket queue, all arriving customers receive a numbered ticket upon arrival. A ticket queue has the monitor displaying the number being served, which can be confirmed by all customers. We call the ticket position the difference between the issued ticket number and the number displayed on the monitor. By confirming the ticket position, customers may balk; that is, abandon service and leave the system. However, due to balks, the actual number of customers waiting service is not necessarily the same as the ticket position. Because we cannot actually see the actual number of customers waiting service, it is important to obtain its distribution. In this paper, we study the M/G/1 ticket queue such that a customer balk with a probability depending on its ticket position upon arrival. Note that customers can abandon the system only on arriving. To analyze the above model, we propose the approximated ticket model. We investigate the embedded Markov chain of the joint stochastic process of the actual number of customers waiting service and the ticket position of the approximated ticket queue. We derive the stationary distributions of the ticket position and the actual number of customers waiting for service. Furthermore, we evaluate the accuracy of the approximate ticket queue by numerical experiments.

3 - Moments for the stationary workload of an M/PH/1 queue with workload-dependent processing speed and vacations
Yutaka Sakuma, Onno Boxma, Tuan Phung-Duc

We consider an M/PH/1 queue with workload-dependent processing speed and vacations. This queueing system has the following features. Firstly, customers arrive according to a Poisson process and their service requirements are i.i.d. phase-type random variables. Secondly, the processing speed of the server is a piecewise-constant function of the workload. Finally, the server switches off when the system becomes empty, and it becomes active again when the workload goes over a certain threshold. For the stationary workload in the system, we obtain the moments of any order in a computable form.

4 - Stationary analysis of the Join the Shortest Orbit Queue with a Priority Line
Ioannis Dimitriou

We consider a retrial system with two infinite capacity orbits and a finite capacity priority line. Arriving job are primarily routed to the priority line. If an arriving job finds the priority line fully occupied, it is forwarded to the least loaded orbit queue and in case of a tie it is forwarded to an orbit randomly. Orbiting jobs of either type retry to access the server independently. We investigate the stability condition, and obtain the equilibrium distribution by using the compensation method. Some tail asymptotic results are also discussed.

■ WB-50

Wednesday, 10:30-12:00 - Virtual Room 50

Decision Support for Intelligent Energy Management

Stream: OR for intelligent Energy Services
Invited session
Chair: *Vangelis Marinakis*
Chair: *Massimo Bertoncini*
Chair: *Antonello Monti*

1 - Predictive and prescriptive analytics for improved Energy Performance Certificates Reliability
Gema Hernandez Moral, Jose L. Hernandez, Sofía Mulero, Ivan Ramos, Francisco Javier Miguel, Susana Martin

Energy Performance Certificates (EPC) have been in place since the implementation of the Energy Performance of Buildings Directive (2010/31/EU), and even when they have raised significant awareness in the performance of buildings, they have not been exploited to their full potential. Some of the main reasons lie in the complexity of the calculation methodologies, lack of trust from the final users, interoperability among data sources and their quality, which does not match with real buildings energy consumption. As a consequence, their potential to be used as a powerful tool to boost the energy refurbishment market (as current trends such as the Renovation Wave strive for) is strongly diminished. To overcome these challenges, Big-Data techniques offer a golden opportunity where data coming from smart meters, as well as other contextual data sources, are merged to delve into the implementation of Big-Data analytics. They support bridging the gap between calculated energy performance and real consumption that can be easily understandable by the public. The use of vast heterogeneous cross-domain and cross-stakeholders amounts of data in a harmonised way is then pivotal. Thus, next generation EPC may be deployed, which improve reliability and comprehensibility. These will be tested within the BD4NRG project, where predictive and prescriptive analytics are applied into multiple and diverse building typologies with the aim of demonstrating its replicability and scalability.

2 - Applied energy disaggregation framework to support behavioural energy efficiency through intelligent energy management
Konstantinos Koasidis, Evangelos Spiliotis, Nikolaos Doumouras, John Psarras

Behavioural energy efficiency is among the top European priorities to reduce energy consumption. To access this potential, intelligent energy management and artificial intelligence are used to provide end-users with information and advices to increase efficiency. Such algorithms usually rely on vast amounts of data from IoT devices. However, most households are rarely in possession of equipment to such extent. For this purpose, ATOM, which has received funding from the Hellenic Foundation for Research and Innovation and the General Secretariat for Research and Technology [HFRI-FM17-2566], introduces personalised apps to support behavioural energy efficiency. Energy disaggregation is used within the apps to provide appliance-level information, avoiding extensive use of smart meters. Still, to achieve adequate accuracy, algorithms either rely on preordained databases, which are not always applicable, or the collection of data for large periods, risking end-users' losing interest in the process. Here, we explore common energy disaggregation algorithms, like Factorial Hidden Markov Models, Combinatorial Optimization, Decision Tree Regression and Long Short-Term Memory, to inform ATOM's behavioural decision support tools and establish an applied energy disaggregation framework that reduces required amount of data, total time of collection, and equipment cost to support intelligent energy management without sacrificing accuracy. A case in a typical Greek household is presented.

3 - "Graph model representation for buildings applications"
Nikos Dimitropoulos, Panagiotis Kapsalis, Zoi Mylona, Haris Doukas

Data that are generated from buildings, either directly with smart meters or indirectly from external data sources, are continuously growing. As they keep growing, their terminology does not follow the same structure, as they are being generated from different data sources and thus the ability to analyze and extract insights from them is restricted from the lack of harmonization. In applications, such as intelligent energy systems, building automation and controls, energy prediction and smart building services, data quality is critical to provide innovative services using Artificial Intelligence based (i.e., Machine Learning, Deep Learning) techniques. To exploit these data, gain insights and create solutions with added value, a framework for common use should be applied. In this context, the aim is to create a solution that takes into consideration the different type of ontologies of the building and its attributes, and to create a data model, using graph model representations. Under unique data models, the different features of the building and their dependencies, will enable optimal querying when data are accessed, and intelligent reasoning between typologies. To do that, several different datasets are exploited, which incorporate building attributes and can be applicable to multiple Big Data applications, and the findings are presented as graphical representations of the graph models.

4 - AI models, Visual Analytics and Querying for Big Data in the Energy Sector
Gerasimos Anastasatos, Vagelis Karakolis, Vangelis Marinakis, Haris Doukas

Today's energy systems and smart grids produce large volumes of data on a daily basis. These data are exploited by their owners through specific applications. However, the utility of these data does not approach its full potential. This is because, on the one hand applications are intended to perform a specific task, while on the other hand, oftentimes the owners of these data lack technical and analytical skills to get, process, and analyze the data. Moreover data silos, caused by technological barriers and/or organizational culture prevent organisations that have significant amounts of data and know-how from sharing them with other interested parties even if it would be beneficial for the common good. Last but not least, the combination of these data with sources from other domains could significantly improve the accuracy of several services. However, for the time being, this is not feasible due to standardization and interoperability issues.

This publication proposes a technical solution that enables visual analytics, AI models development, and efficient querying of heterogeneous (Big) Data sources for the Electric Power and Energy Systems (EPES) sector. This solution has been designed under the context of the EU funded H2020 research project BD4NRG that aims at addressing the emerging challenges in big data management for energy and enabling Business to Business data sharing to unlock new market opportunities.

■ WB-55

Wednesday, 10:30-12:00 - Virtual Room 55

Integrating machine learning in optimization methods I

Stream: EURO Working Group Data Science meets Optimisation
Invited session
Chair: *Kevin Tierney*

1 - Reinforcement Learning enabled optimisation for home delivery services
Yimo Yan, Yong-Hong Kuo

During the global pandemic lockdown, home delivery becomes an ever-important element in urban areas. However, scheduling delivery slots for multiple workers, vehicles and customers results in combinatorial possibilities and requires substantial computational efforts. Traditional heuristics and exact methods are bounded by the cost-accuracy trade-off.

Inspired by the use of high-efficiency self-attention Neural Network Architectures for language processing, we applied a similar architecture with reinforcement learning to solve delivery scheduling problems. These architectures can accurately capture the relationship between different input elements. Our model has the objective of minimising total delivery time and balancing workload while considering the stochasticity of preparation and delivery time. It can solve order assignment problems at a much faster pace with satisfactory accuracy after adequate training. Besides, we also designed a post-processing Neural Network to identify wrong digits in the output.

2 - Improving Clarke and Wright Heuristic with Machine Learning

Clément Legrand, Luca Accorsi, Laetitia Jourdan, Diego Cattaruzza, Marie-Eléonore Kessaci, Daniele Vigo

In routing problems, the Clarke and Wright (CW) heuristic is a famous constructive heuristic. Although this heuristic does not generate very good solutions, several enhancements have been provided over the years. We present here a variant of CW that uses a trained neural network, which tries to distinguish between good edges and bad edges of an instance. In this variant, called subLists, the list of basic savings is cut into smaller sub-lists of fixed size. Preliminary experiments show that we cannot choose a single size for sub-lists able to obtain the best initial solution for all instances. To fix this problem, we propose an other variant, called Best SubLists, in which we define a list of sizes, and we keep the best solution among the solutions obtained. For the experiments, we use the Uchoa set of instances to train the neural network. The Uchoa set is very challenging, mixes various instances, and is commonly used to test new algorithms for the CVRP. With the variant SubLists, we obtain in average slightly better solutions than with CW, and considering the preprocessing of the training of the neural network and of the predicted probability of each edge, we also get a similar time to the CW. However the most promising results are given by our variant Best SubLists, which improves in average the solutions by almost 1.5%. It is also important to note that this latter variant needs more computational effort.

3 - Smarter automatic algorithm configuration for the capacitated vehicle routing problem

Pieter Leyman, Holger Hoos

Assume that you want to solve a rather difficult, say NP-hard, problem. You could design a new metaheuristic algorithm with components tailored to the problem you wish to solve. Typically, these components are associated with a multitude of, often hard-coded, design choices. Additionally, most if not all metaheuristic algorithms contain parameters (e.g., the population size in a genetic algorithm), which can have a major impact on the performance obtained for specific types of problem instances.

Automatic algorithm configuration (AAC) is concerned with achieving high performance for algorithms by selecting the suitable parameter values. Such an approach replaces manual, often irreproducible and tedious, configuration and can lead to better algorithm performance. This algorithm configuration problem, which is an optimization problem in its own right, can fortunately be solved automatically by making use of general-purpose algorithm configurators, such as SMAC, ParamILS and irace.

In this talk, we discuss how we have applied AAC to a state-of-the-art metaheuristic algorithm for the capacitated vehicle routing problem, and show how AAC can improve performance. We furthermore show how the results of our AAC approach can be further enhanced by focusing on the most important algorithm parameters. This way, we can reduce computation time, while still obtaining an improved performance compared to the default parameter settings chosen by a human domain expert.

4 - Efficient Active Search for Combinatorial Optimization Problems

André Hottung, Yeong-Dae Kwon, Kevin Tierney

Recently numerous machine learning based methods for combinatorial optimization problems have been proposed that learn to construct solutions in a sequential decision process via reinforcement learning. While these methods can be easily combined with search strategies like sampling and beam search, it is not straightforward to integrate them into a high-level search procedure offering strong search guidance. Bello et al. (2016) propose active search, which adjusts the weights of a (trained) model with respect to a single instance at test time using reinforcement learning. While active search is simple to implement, it is not competitive with state-of-the-art methods because adjusting all model weights for each test instance is very time and memory intensive. Instead of updating all model weights, we propose and evaluate three efficient active search strategies that only update a subset of parameters during the search. The proposed methods offer a simple way to significantly improve the search performance of a given model and outperform state-of-the-art machine learning based methods on combinatorial problems, even surpassing the well-known heuristic solver LKH3 on the capacitated vehicle routing problem. Finally, we show that (efficient) active search enables learned models to effectively solve instances that are much larger than those seen during training.

■ WB-58

Wednesday, 10:30-12:00 - Virtual Room 58

Personnel scheduling in health care (2)

Stream: ORAHS: OR in Health and Healthcare
Invited session
Chair: *Jens Brunner*
Chair: *Markus Seizinger*

1 - A simulation-based approach for optimal physician scheduling in the emergency department

Anika Johlke

This study investigates the stochastic arrival behavior of patients in interdisciplinary emergency departments to efficiently allocate the limited resource of physicians to ultimately minimize patient waiting times and the numerous health risks associated with crowding. The patient arrival process is modeled as an inhomogeneous Poisson process whose intensity function is estimated on real data from the University Hospital in Jena, Germany. Furthermore, a multivariate distribution of treatment times was derived, including information on explanatory variables such as the triage category. Based on both, a flexible discrete event simulation is built, which is applicable to new data, and combined with the Simulated Annealing optimization algorithm to derive a distribution of waiting times. The efficiency of the optimized duty rosters is measured not only by the mean value (as is usually the case), but also by the 90% quantile of waiting times. Although the current roster complies with ESI regulations, better performing rosters were easily identified. Furthermore, we illustrate the usefulness of our model by showing that the disregard of triage-based priority treatment leads to suboptimal duty rosters and have a significant impact on patient waiting time. Due to the complex structure and sensitive nature of an emergency department, we consider the use of a simulation-based analysis tool for physician rostering as necessary, especially in German hospitals.

2 - Physician Scheduling at a Department of Internal Medicine

Clemens Thielen, Jan Boeckmann

Physician scheduling is an important task within personnel planning in hospitals and has a large impact both on the efficient operation of the hospital and on employee satisfaction. Good schedules should not only satisfy many complex constraints resulting, e.g., from minimum rest times or required staffing levels, but also achieve a fair distribution of the workload and adhere to the preferences of the planned personnel.

This talk presents a practical physician scheduling project that has recently been started in collaboration with a medium-sized department of internal medicine of a German hospital. The problem faced at the department consists of assigning shifts to physicians both within the normal wards of the department as well as on the intensive care unit (ICU) and the chest pain unit (CPU) over a planning horizon of four to eight weeks. We present the structure of this physician scheduling problem as well as the integer-programming-based solution approach used within the project. Moreover, we demonstrate the projected practical implementation, which uses a web interface to collect all necessary input data and display the computed schedules.

3 - IMPROVEjob - Participatory intervention to improve job satisfaction of general practice teams - Part: workflow management

Matthias Grot, Brigitte Werners, Lukas Degen, Birgitta Weltermann

Perceived high chronic stress is twice as common among German general practitioners (GPs) and non-physician medical staff compared to the general population. The reasons for this are multifactorial. Practice-related factors, such as stressful patient-staff interactions, poor process management of waiting times and lack of leadership play a key role. This publicly funded study evaluates the effectiveness of the newly developed participatory, interdisciplinary and multimodal IMPROVEjob intervention to improve job satisfaction among practice staff. The intervention aims at structural and behavioral prevention for physician practice owners and other practice team members. It consists of two leadership workshops, a toolbox with supplementary material and an implementation phase with regular contact with so-called IMPROVEjob facilitators. To improve workflow management in practices, we use simulation and optimisation models. Thus, we attract awareness of possible improvements in process structures. Opportunities for restructuring work processes are identified which aim at both behavioural and working condition improvements. This study is funded by the German Federal Ministry for Education and Research (grant numbers 01GL1851D, 01GL1751B, 01GL1751A, 01GL1751C).

4 - Optimized Planning of Dual Vocational School Operations in the German Health Care System: Linear Models, Algorithms, and Case Study at University Hospital Augsburg

Markus Seizinger, Jens Brunner

We investigate a problem in vocational school planning for the nursing profession in Germany and other countries with a dual vocational system, which closely combines theoretical and practical education and is highly regulated by federal legislation. The apprentices rotate through vocational school-blocks followed by assignments to hospital units, where they receive practical education. The length and contents of both parts of their education is regulated in high detail. Hospital units offer the vocational schools some slots for apprentices. They expect the schools to send just enough apprentices to be trained and educated. We create two mixed-integer programming models to optimally solve the underlying planning problems of (1) scheduling classes to theoretical and practical education blocks and (2) assigning apprentices to hospital units according to their current progress. The first model determines the number and length of school- and work-blocks on a class level, ensuring the given school-curriculum and leveling the number of students available for the hospital units. Its result is input to the second model, which finds an individual unit-assignment for every apprentice fulfilling all remaining and more detailed curriculum requirements. Furthermore, it tries to exploit the units' educational capacities as good as possible. To solve the both models we develop a heuristic procedure that decomposes the models and enables good feasible solutions in a short amount of time.

■ WB-60

Wednesday, 10:30-12:00 - Virtual Room 60

Real-world applications of cutting, packing and scheduling

Stream: Cutting and Packing
Invited session
Chair: *Dario Vezzali*

1 - Optimization of a real-world two-stage flexible flow shop problem with workers allocation

Beatrice Bolsi, Vinícius Loti de Lima, Thiago Alves de Queiroz, Manuel Iori

We study an optimization problem which is faced daily by meat industries and other manufacturing companies as well. In our case study, a set of orders have to be produced by following two stages: in the first stage, the meat is processed (cut) on a given bench, and in the second stage it is sent to a conveyor to be packed into disposable trays. Benches and conveyors are seen as heterogeneous parallel machines, and their productivity depends on the number of workers operating each. The problem has many practical constraints: orders have release and due dates, as well as a maximum waiting-time and a transportation time between the first and second stage; orders are organized into families causing family-related setups on the machines; a work-day is divided into up to two shifts, each characterized by time-related constraints. The decisions involve the total number of workers needed on each period, their distribution on the machines, and the sequencing of the orders. The problem has a lexicographic function based on the minimization of the number of tardy jobs, the number of setups, and the total production cost. To efficiently solve the problem, we propose a multi-start random constructive heuristic that: (i) sorts the orders at random; (ii) considers different allocations of workers to machines; and (iii) schedules the orders in the first and second stages by following a list of priorities. Extensive computational tests prove the effectiveness of the proposed solution method.

2 - Scheduling of parallel print machines with sequence-dependent set-up costs: A real case study

Alberto Locatelli, Manuel Iori, Marco Locatelli

In the present work, we consider a real-world scheduling problem arising in the color printing industry. The problem consists in assigning print jobs to a heterogeneous set of flexographic printer machines, as well as in finding a processing sequence for the sets of jobs assigned to each printer. The company's aim is to minimize total tardiness and total setup times. The machines are characterized by a limited sequence of color groups and can equip additional components (e.g., embossing rollers and perforating rolls) to process jobs that require specific treatments. A job is characterized by a sequence of colors and, during its print, each color takes exactly a color group, respecting a specific chromatic order. The process to equip a machine with an additional component or to clean a color group takes a long time, with the effect of significantly raising the set-up costs. Furthermore, the time required to clean a color group between two different jobs depends directly on the involved colors. If the two colors are similar, it is sufficient to apply a fast and partial cleaning of the color group, otherwise the cleaning operation has to be complete. To tackle the problem, we propose a constructive heuristic followed by several local search procedures that are used one after the other in an iterative way. Extensive tests on real-world instances provided by the company prove that the proposed algorithms can obtain very good-quality solutions within a limited computing time.

3 - Smart-Meter Installation Scheduling in the Context of Water Distribution

Dario Vezzali, Manuel Iori, Carlo Alberto Magni, Andrea Marchioni, Davide Baschieri

In this work, we propose a Mixed Integer Linear Programming (MILP) formulation to model a Smart-Meter Installation Scheduling Problem (SMISP) in the context of water distribution. The model has been used to solve a real case study from a multi-utility company operating in the Italian market. Specifically, in compliance with the European and the Italian regulations on metering, a distribution company is obligated to periodically control meters and substitute them in case they have reached their lifespan. In the examined case study, the multi-utility company has opted for a massive substitution plan in order to install innovative "walk-by smart-meters" in place of traditional mechanical meters. The MILP formulation aims at integrating both the operational and the financial perspective of the SMISP. In particular, the objective function has been carefully defined in order to maximize the Net Present Value (NPV) of the massive substitution plan, including the operational savings produced by using the walk-by smart-meters, the additional incomes originating from the gradual charge of substitution costs on customers' invoices as considered by the Italian Authority, the depreciation of walk-by smart-meters, the investment costs, and the impact of income taxes on the objective function. The final goal of the proposed formulation is to define a scheduling for the massive substitution plan that satisfies a number of operational constraints and produces the maximum NPV.

■ WB-62

Wednesday, 10:30-12:00 - Virtual Room 62

Sırma Zeynep Alparslan- Gök

Stream: Keynotes
Keynote session
Chair: *Gerhard-Wilhelm Weber*

1 - Recent advances in Cooperative games and their potential on Economics and Operations Research situations under uncertainty
Sırma Zeynep Alparslan Gök

Cooperative game theory has been enriched in recent years with several models which provide decision-making support in collaborative situations under uncertainty. Such models are generalizations of the classical model regarding the type of coalition values. Thus, the characteristic functions are not real valued as in classical case; meaning that payoffs to coalitions of players are known with certainty; but they capture the uncertainty on the outcome of cooperation in its different forms such as interval uncertainty, grey uncertainty, fuzzy uncertainty. To incorporate uncertainty in cooperative games is motivated by the real world, where noise in observation and experimental design, incomplete information and further vagueness in preference structures and decision making play an important role. This causes a great mathematical challenge which is approached and well understood in the case of interval uncertainty. This talk surveys and improves recent advances in understanding the mathematical foundations and interdisciplinary implications of cooperative games under uncertainty as well as the connections of Operations Research approach to economics and its related instruments.

Wednesday, 12:30-14:00

■ WC-02

Wednesday, 12:30-14:00 - Bulding A, Room A5

MCDA Methods 2

Stream: Multiple Criteria Decision Analysis
Invited session
Chair: *Sarah Ben Amor*

1 - Consolidation of criteria weights and veto related preference structures in multi-attribute utility models for sorting
Andrej Bregar

Multi-attribute utility models have been recently extended with veto related preference structures, which are adopted from the outranking approach and allow for non-compensation of unsatisfactory preferences. The more selective that the effect of veto is with regard to a criterion, the more this criterion influences the evaluation of alternatives. Veto hence reflects the importance of criteria and exhibits similar preference structures as criteria weights. In this study, the correlation between veto and criteria weights is introduced and methodologically applied to MAUT based sorting models. An algorithm to infer criteria weights from veto related information is proposed, with which selective strengths of veto degrees are calculated to compare the magnitudes of veto, while strengths of veto assignments are used to determine the influence of veto criteria on the deterioration of categories into which alternatives are sorted. Strengths of non-compensatory veto criteria are then projected into weights of compensatory utility criteria. To sort alternatives, hierarchical and linear ascending procedures are applied and assessed. The experimental study reveals the characteristics of indirectly derived criteria weights and the influence of veto. Several quality factors are considered, such as the validity of weights, accuracy of results, richness of information and ability to discriminate conflicting alternatives. Weights are also compared to standard ROC and RS surrogate weights.

2 - A robust multiple-criteria aggregation procedure for mixed evaluations
Sarah Ben Amor, Ahmet Kandakoglu, Anissa Frini

In most multicriteria decision aiding situations, the presence of different types of information imperfections such as uncertainty, imprecision and ambiguity, is inevitable. MCAPmix, a Multiple-criteria aggregation procedure for mixed evaluations, is a ranking procedure that provides a framework to deal with these imperfections on the alternative evaluations using stochastic dominance concepts and distance measures between pairs of alternatives. In this paper, a new multiple-criteria approach addressing the robustness concern is proposed by extending MCAPmix to deal with imperfections on the technical parameters. Different plausible parameters sets are generated to define different versions of the decision problem. The preorders obtained for the different versions are combined into a synthesis preorder. A robustness criterion is then defined based on a distance measure to assess the robustness of the synthesis preorder. In addition, the simple weighted sum to aggregate the local preferences into global ones between the pairs of alternatives, is replaced by an ELECTRE type aggregation in the new procedure. The proposed approach is illustrated through a case study.

3 - Developing an Exact Zoning Optimization Model for Marine Spatial Planning(MSP)
Mohadese Basirati, Patrick Meyer, Romain Billot, Erwan Bocher

Systematic approaches to marine spatial planning (MSP) have recently attracted more attention as an efficient planning tool. MSP is a process gathering multiple users of the ocean with the objective to simplify decisions regarding the sustainable use of marine resources. One of the challenges in MSP is to determine an optimal zone for the activity of one marine user, while taking into account the activities of the other actors. Such spatial zoning approaches are usually formulated as non-linear multi-objective models, which are solved using stochastic search algorithms, which leads often to sub-optimal solutions. In this paper, we propose to model the problem as a Multi-Objective Mixed Integer Linear Program. The model is formulated for raster data and it aims at maximizing the interestingness of the area of the zone dedicated to one actor, while maximizing its spatial compactness. We study two resolution methods: first a weighted-sum of the objectives, and second an interactive approach based on an augmented version of the ϵ-constraint method. To validate and study the model we perform experiments on artificially generated data.

■ WC-03

Wednesday, 12:30-14:00 - Bulding A, Room 3A

Combinatorial Optimization in Health and Social Care II

Stream: Combinatorial Optimization
Invited session
Chair: *Helena Ramalhinho Lourenco*

1 - A bi-objective optimization approach for the synchronized home health and social care problem
Bruno Vieira, Jesica de Armas, Helena Ramalhinho Lourenco

With the continuous increase in longevity worldwide, elderly population requiring domiciliary health and social care has been continuously growing over the years. Planning combined home health and social services has shown to be a very difficult task for current decision-makers, not only due to the high number of working regulations and caretaker-related necessities that need to be considered, but also due to the need for synchronizing both types of services. For instance, a (social) caregiver may be required to bath a certain caretaker before a doctor's visit. Or a hospital nurse may need to collect a blood sample from a caretaker before a social caregiver gives him/her the first meal of the day. Moreover, it is highly desirable that caretakers are visited by the same caregiver in all of their appointments (loyalty). The complex and multi-objective nature of the synchronized home health and social care problem (synchro-HHSCP) has been calling for the development of automated and holistic planning systems that are able to obtain efficient solutions in reasonable computational times. In this work, we combine (meta)heuristic methods and mathematical programming to optimize routing and scheduling decisions for the synchro-HHSCP. We use real data from current care providers in the Barcelona area to test our models and provide insights on the tradeoff between the associated operating costs and loyalty levels by comparing our solutions to those obtained by actual practitioners.

2 - Optimal COVID-19 vaccination centers distribution
Laura Portell, Daniel López Badell, Jesica de Armas, Helena Ramalhinho Lourenco

It is of great importance to stop the spread of COVID-19 as soon as possible. Vaccines are one of the best assets to achieve this goal making the associated logistic optimization process a priority.

In particular, it is extremely important to identify the best location of the vaccination centres for a given city. In this work we present a new optimisation model which identifies the optimal vaccination locations in a city, taking into account the importance of prioritising people with a higher mortality risk due to COVID-19. The features and constraints used include age, health issues, proximity to vaccination centres, amount of vaccine available per type, vaccination capacity per centre, and the need to retain vaccines to account for second dosages. The model is adaptable, it allows to find vaccination centres for different profiles such as healthcare staff, teachers and staff with face-to-face roles to mention a few. The results that we present use data from the city of Barcelona but our techniques could be applied to any other city.

3 - Routing Solutions to help in Pandemic Outbreaks: A Case Study
Helena Ramalhinho Lourenco, Pedro Martins, Antonio Trigo

The Covid-19 Pandemic led to a challenge in many Social and Health Organizations that need to implement solutions and responses to new problems, or old ones in a higher dimension, in a very short time. In this work, we propose a simple routing system that can be used in any organization that needs to plan the collection or distribution of products during the pandemic. Several organizations collaborated with the researcher team, among them: Creu Roja (Red Cross) to deliver food and first-necessity products to families in quarantine; Banc d'Aliments to distribute food to social restaurants; and medical organizations to collect Covid-19 samples or to distribute the vaccines to the vaccination points. All these problems can be seen as applications of the Capacitated Vehicle Routing Problem, in the open and close versions. We have implemented an Iterated Local Search algorithm and decided to incorporate it in Microsoft Excel and Microsoft Bing Maps to facilitate its applicability. In these organizations, the planning is usually done by volunteers or no-expert planners, therefore the application must be easy to use. We describe real applications in the city of Barcelona and numerical results of several applications (with pseudo-real data, due to confidential reasons). We will also discuss the implications and benefits of this tool from the point of view of the mentioned organizations and their users.

■ WC-04

Wednesday, 12:30-14:00 - Bulding A, Room 3B

Queues with Strategic Customers III

Stream: Queues with Strategic Customers
Invited session
Chair: *Yiannis Dimitrakopoulos*

1 - Physician dual practice in the framework of strategic queueing: Patients' equilibrium behavior and physicians' optimal split among practices.
Yiannis Dimitrakopoulos, Dimitris Andritsos, E. Lerzan Ormeci

In the present work, we analyze the dual physician practice in a strategic queueing framework, considering that patients make strategic decisions for treatment among the public sector, a private-only physician, or a dual physician in private. We model both the public and the physicians' private practices as separate parallel M/M/1 queues with adjusted service rates. The service rate in public depends on the number of physicians working in the public sector, whereas the service rate at each private practice is set to maximize the physician's utility in a trade-off between leisure and income. We formulate a Stackelberg game among patients and private physicians, where physicians act as leaders and announce their time-availability in their private practice, and their fee for treatment. The time availability of a private physician is translated to the adjusted service rate, and it is limited in the case of duals. Next, patients, who act as followers, choose strategically between the public sector or a physician's private practice concerning the waiting time for treatment without observing any queue length.

We explore in a unified manner, the optimal proportion of time that physicians are willing to invest in private practice in the presence of dual-practice as well as the corresponding effect on patients' equilibrium selection. Finally, we examine the physicians' optimal split between the public and private market.

2 - Strategic reneging in queueing systems with server vacations/failures
Dimitrios Logothetis, Antonis Economou, Athanasia Manou

We consider a single server Markovian queueing system that alternates between on and off periods. Strategic customers arrive at the system according to a Poisson Process and observe the server state and the number of waiting customers. The customers are delay-sensitive and receive a reward upon service completion. At the beginning of an off period (i.e., when a breakdown occurs), the customers may prefer to abandon the system. The purpose of this work is to investigate the value of reneging on the equilibrium social welfare of the system. To this end, we consider two scenarios regarding the customers' strategic dilemma. In the first one, reneging is not allowed, and customers decide whether to join the system or balk. In the second, the balking option is not available. For both scenarios, we identify explicitly the equilibrium strategies. Given the equilibrium strategies, we obtain the stationary state distribution and compute the key performance measures for each scenario. Then, we introduce the Value of Reneging (VoR) which provides a measure for the influence of reneging on system's performance. The study is further complemented with a fluid queue approximation for the model and the corresponding equilibrium analysis. The analysis is supported by numerical experiments and graphical illustrations that demonstrate various effects of reneging behavior in this system.

■ WC-05

Wednesday, 12:30-14:00 - Building Δ, Room Δ105

Optimization under Uncertainty in Energy and Waste Management

Stream: Stochastic and Robust Optimization
Invited session
Chair: *Eric Perim*

1 - Application of Reinforcement Learning in Waste Incineration Plants
Martin Schlappa, Stefan Spinler, Jonas Hegemann

More than 60 waste incineration plants (WIP) are active across Germany. To date, some of the WIPs are - at least in part - operated manually by human operators (HO). To maximize steam production under constraints such as legal emission thresholds and technical machine limits, HOs can influence the combustion process in several ways, e.g. by changing the volume of waste being burned or the primary airflow. Managing the combustion process is a rather complex task. To handle this complexity, HOs tend to rely only on a few possible operational levers and on infrequent interventions. As a consequence, the combustion process is currently managed rather inefficiently, which can be seen in the significant fluctuations in performance across HOs and even for one HO. This paper investigates how reinforcement learning (RL) enhances process automation and thus helps WIPs optimize the combustion process, e.g., by making more frequent and diverse interventions. Following the typical RL approach, an agent is trained via "trial and error" given a reward function. Since the actual equipment cannot be used as the training environment, a simulation ("digital twin") of the WIP is built first using a neural network to act as the offline environment to train the agent. Then, the agent is trained using a RL algorithm (DQN). Our work demonstrates that RL algorithms can be fundamental to enable more stable operations, higher steam output and lower emissions in WIPs.

2 - Multi-node Bidding Into Electricity Markets using the Transmission Constrained Residual Demand Approach
Abraham Alvarez-Bustos, Andrew Rosemberg, Bruno Fanzeres

This work explores the characterisation and implementation of the Transmission-Constrained Residual Demand Derivative (TCRDD) derivative to optimise the profit of a set of generators in an offer-based electricity market cleared by an optimal power flow (OPF) program, extending the existing literature. Just as with the original method proposed by the authors of this algorithm, the offers presented by a firm are optimised based on the TCRDD approach, which is calculated using a solved OPF without changing existing OPF algorithms and programs. The approach is generalised to a multi-generator case, where one firm owns multiple generators at multiple locations in the system. This multi-node approach aims to determine the optimal quantity/volume to offer which maximises the profitability of the generators as a whole. Furthermore, using the developed approach, the study also presents a basic bidding strategy on maximising the profits of a paired bidding (Offer/Demand) for virtual participants of the market in the presence of transmission constraints. Finally, we discuss what further extensions are needed to apply this strategy in full by virtual participants.

3 - Finding predictable low-dimensional spaces in electricity price data
Eric Perim, Wessel Bruinsma

Locational marginal prices are part of the solution to the optimal power flow (OPF) problem, which is a complex optimisation with many constraints and time-varying inputs. Consequently, electricity prices in real grids tend to be volatile and sometimes exhibit extremely large "price spikes".

Because of the high dimensionality and erratic behaviour of electricity prices, their dynamics are difficult to model. Instead of modelling price dynamics in full, one might try to simplify the modelling task by searching for a better-behaved low-dimensional subspace. Compared to the high-dimensional "price space", this subspace could be significantly easier to model. In this talk, we will explore the idea of well-behaved subspaces to construct hedges against hard-to-predict price behaviour, like spikes.

Finding a lower-dimensional representation of the data is the basis of many statistical models, such as PCA and factor analysis (FA). Unlike PCA, FA, and other related dimensionality reduction techniques, we propose to find the subspace by directly optimising how well the subspace can be modelled, which alleviates certain issues aforementioned techniques in our setting.

4 - Analysing decarbonizing strategies in the European power system applying stochastic dominance constraints
Sebastiano Vitali, Ruth Dominguez

We develop an analysis of the efficiency of the strategies to be followed to attain the emissions targets established by the European Commission in the Energy Roadmap 2050. A multistage investment model in generating and storage capacity from the point of view of a central planner is presented, considering long-term uncertainties such as the demand growth and the investment and fuel costs in the decision-making process. To evaluate the wellness of the expansion strategies according to the CO2 emissions generated and the total cost, second-order stochastic dominance constraints are introduced in the model. This approach allows to obtain better expansion strategies enforcing acceptable distributions of CO2 emissions. The numerical study is carried out considering the case of the European power system. The predictions and suggestions made by the European Commission towards 2050 are the basis to define the benchmark solutions, whose outcomes are analyzed. The results obtained from this study highlight that a renewable capacity of at least 2900 GW is needed to attain a net zero CO2 emission European power system. The strategy based on carbon capture and storage does not reduce effectively CO2 emissions while it represents an expensive alternative. Including stochastic dominance in the optimization model allows to obtain less expensive alternative expansion strategies with comparatively lower CO2 emissions in the worst scenarios.

■ WC-06

Wednesday, 12:30-14:00 - Building Δ, Room Δ103

Optimization in robotic warehouses II

Stream: Automated Warehouse System
Invited session
Chair: *Alexander Hübner*

1 - Optimal design for the telescopic lift Autonomous Case-Handling Robot system
Zhe Yuan, Yeming Gong

With the increase in rents and prices of commercial land, the demand for intensive storage in warehouses increases. Meeting intensive storage and high throughput has become a challenge for automatic warehouse optimization. This study focuses on the telescopic lift Autonomous Case-Handling Robot, an intelligent "goods-to-person" order picking system. We build a closed queueing network to estimate the maximum throughput and provide design rules to determine the optimal number of robots and their capacities. We validate the analytical model by numerical experiments to analyze the operating strategies. Compared with the robotic mobile fulfillment system, this system provides higher efficiency, greater flexibility, and higher storage density.

2 - Finding the Right One: Decision Support System for Selecting Robotized Order Picking Solutions
Fabian Lorson, Fabian Schäfer, Alexander Hübner

Enabled through recent advances in technology coupled with the advent of new system providers and decreased price points, robotic order picking solutions (e.g., automated guided vehicles) evolved as a surging market. Such systems aim at reducing labor cost, using available space more efficiently, and increasing throughput rates. As implementation projects and the variety of solutions are rising, managers face the decision which one to select for their specific business case. However, appropriate decision support systems for this strategic problem are missing. We contribute by proposing a mathematical optimization model that assigns each stock keeping unit the most suitable solution. In particular, we minimize investment, running and error cost while adhering to product and solution related characteristics (e.g., physical constraints), which previous research has been neglecting, but are of outermost concern when robotic devices are involved. Furthermore, we identify decisive input factors that feed our model using expert interviews. We also screen existing work on strategic decision support systems in warehousing. Using a set of novel solutions and generic data, we find significant cost reduction potential compared to both manual picking and an experienced-based allocation. We will further validate our model with industry data, and expand system solution ranges. Our findings give new insights into which robotic devices are best suited for different configurations.

■ WC-07

Wednesday, 12:30-14:00 - Building Δ, Room Δ102

Cutting and packing applications II

Stream: Cutting and Packing
Invited session
Chair: *Amalia Nikolopoulou*

1 - A packing software for the container loading problem with regular and irregular-shaped cargo
Germán Fernando Pantoja Beanvides, Juan Pachon Pachon, Daniel Cuellar-Usaquen, Camilo Quiroga, Luis Miguel Escobar Falcón, Laura Escobar, David Álvarez-Martínez

Currently, several packing software tools aim to model the largest number of packing constraints possible to increase their application spectrum, i.e., the same software can be used to solve different packing problems that an individual or a company may face. These tools have focused on regular-shaped cargo, generally boxes, due to the complexity that irregularity implies. We propose a novel approach for the container-loading problem, considering regular-shaped and irregular-shaped cargo. Our approach uses simulated movements and forces that allow the items within the container to change their position and orientation. Our methodology verifies the containment, the non-overlapping, and the non-intertwining constraints. We compared the performance of our approach with methodologies that solve regular and irregular 3D packing problems. In this work, we have considered the user experience when an individual uses this approach to solve a packing problem. Therefore, we designed an intuitive interface that assists the user at each step of the process of solving a packing problem. This interface allows the user to create or import an item to pack, set up the container and constraints to customize the packing problem to solve, and visualize the final packing pattern.

2 - Loading Kitchens into Trailers: A Package Bundling Heuristic
Jakob Schulte, Michael Römer, Kevin Tierney

We address a real world logistics problem arising at a large kitchen manufacturer involving packing sets of boxes containing partially assembled kitchen parts into a trailer. The boxes to be loaded into a trailer are considered as given, and thus, the task considered here is to check if they fit into the trailer or not. While our problem can be viewed as type of container loading problem, it has some challenges in terms of packages and packing constraints. First, the boxes vary greatly both with respect to size and geometry: There are very small and very large packages, and among the large packages, some are very compact while others are very bulky. Second, we take into account about 500 packages that must be stowed in the truck. Third, the packing must respect the order of unloading resulting from the route of the truck. All packages of a customer (a kitchen retailer) must always be loaded together and must not be spread over the entire loading area. To solve this problem, we present a novel multi-start heuristic relying on aggregating packages to bundles. For each customer stop, we repeatedly use a parametrised strategy to group the packages into bundles which are then loaded into the truck. We experiment with different surrogate objective functions to assess the quality of the possible solutions for a customer stop. We present preliminary results with real-world instances and showing that our approach achieves high-quality results in a reasonable amount of time.

3 - A metaheuristic approach for solving large scale vehicle routing problems with cross-docking and loading constraints
Amalia Nikolopoulou, Eleftherios Manousakis, Emmanouil Zachariadis, Panagiotis Repoussis

A key decision for every product consolidation node in a distribution network is the synchronization of inbound and outbound product flows. Among other operational issues, the physical space restrictions limit the number of vehicles that can be simultaneously processed. As a result, the coordination and scheduling of vehicles becomes a hard problem to solve with significant impact on the overall network performance. This paper introduces a new Vehicle Routing Problem with capacitated Cross-Docking. The cross-dock capacity represents the maximum number of products that can be handled simultaneously at the cross-dock at any point in time. The First-In First-Out policy for serving the inbound vehicles at the cross-dock is considered. At first, a mathematical formulation is provided. Next, we present a local search metaheuristic algorithm that is tested on existing as well as new benchmark data sets. Various computational experiments are performed to explore the effect of the cross-dock processing capacity on the total transportation costs and the cross-dock operations. To deal with the additional complexity, a heuristic mechanism and a Constraint Programming optimizer are used as alternative approaches for efficiently evaluating the feasibility of tentative solutions. A performance comparison of these approaches is presented and algorithmic insights are provided.

■ WC-21

Wednesday, 12:30-14:00 - Virtual Room 21

Uncertainty

Stream: Behavioral Decision Making
Invited session
Chair: *Konstantinos Katsikopoulos*

1 - The role of implicit behavioural assumptions in budgeting decisions
Shashwat Pande

In all organizational domains, decision-makers set budgets based on imperfect information. Managers often use simple heuristics to make such judgements. While simple heuristics can be remarkably accurate in individual decision-making settings, it is not clear how strategic interactions between agents might affect the accuracy of such judgements. In this session, I present preliminary evidence from a manufacturing company where promotional spending budgets are systematically underestimated. The results suggest that while managers underweight the impact of natural attributes such as stock-levels and retailer-networks in their budgeting decision, the relative contribution of these attributes towards the variance between actual and budgeted spending is smaller than incorrect expectations on attributes that encode behavioural information. I propose that drawing on the descriptive psychological theory can support the communication of model outputs to decision-makers in cases where routine calculations falter due to implicit behavioral assumptions that may be problematic in practice.

2 - Numerical Cognition and Risky Preference Formation Under Cognitive Uncertainty
Tianqi Hu, Ilkka Leppanen, L. Alberto Franco, Maxwell Shinn

Recent studies show that cognitive uncertainty can affect risk preference. We examine whether this effect depends on the mode of numerical cognition that the decision maker uses to understand the prospects of risky decisions. We examine two distinct modes of numerical cognition, exact and approximate calculation processes. Our results show that the way that cognitive uncertainty affects risk preference depends on the particular mode of numerical cognition operating. When the process involves significant exact calculations, a high level of cognitive uncertainty leads to risk-averse behaviour. In contrast, cognitive uncertainty is not found to affect risk preference when the predominant decision process involves approximate calculations. Moreover, we do not find evidence that cognitive uncertainty induces decision makers to rely on their prior beliefs, which was previously believed to mediate the effects of cognitive uncertainty on risk preference. We also investigate whether different levels of cognitive uncertainty between individuals can be detected by psychometric tests that measure a person's cognitive abilities. Our results show that cognitive uncertainty can be predicted by scores from the Cognitive Reflection Test. We discuss the implications of our results for theory development and real-world applications of risky decision making and suggest some potentially fruitful areas for further research.

3 - Scope of business actors' heuristics and introduction of AI based marketing automation tools
Simone Guercini

The paper focuses on the impact of new marketing automation tools on business actors' decision making process and more in general on their declared judgement and observed behavior. In particular, it is examined how the introduction of AI based marketing automation tools relates to the use of heuristic rules, focusing on the scope of heuristics and the decision makers' adaptive toolbox. "Scope" is (the extention of) the field in which a heuristic rule can be applied (with success). Looking at the scope of a heuristic rule means shifting the attention from the accuracy of the decision-making model to the borders of the context where it is effective (task environment). "Marketing automation" means automatic support for marketing decision in the digital task environment. Marketing automation can use artificial intelligence to manage both strategic tasks (analytics, forecasts, segmentation, etc.) and operational tasks (monitoring contact behavior; e-mailing; promoting actions, etc.). The paper elaborates on 29 ethnographic interviews to 23 business actors including managers of medium level and some top managers and entrepreneurs. The evidence collected suggests that AI can modify the task environment changing the set of problem to solve and rules applied; at the same way, however, AI systems can generate novel conditions of "unquantifiable uncertainty", and expand in this direction the areas "in the wild" in which the heuristics can be used.

4 - Classification in the wild: The science and art of transparent decision making
Konstantinos Katsikopoulos

In the wild refers to situations where, unlike in a typical psychological experiment or decision model, uncertainty cannot be reduced to probability. Jimmie Savage, father of decision theory, argued that even planning a picnic lies outside it. Can decision making in the wild be based on science? Yes. We introduce formal models often absent in psychology. Machine learning also addresses the challenges of the wild. Neural networks and random forests deal with uncertainty but are not transparent. When systems based on these tools are used in financing or in courts, it remains a mystery to loan applicants or defendants why they were denied the loan or bail. Classification in the Wild is committed to increasing transparency. It provides tools easy to understand, teach and execute. The tools allow practitioners to make fast and accurate classifications when no fancy algorithm is at hand as at the site of an accident or suicide attack. Classification in the Wild introduces heuristics that are both descriptive and prescriptive, describing the art of how experienced practitioners decide while also suggesting how to improve it. These heuristics are models of bounded rationality, a term coined by Herb Simon, founder of artificial intelligence and pioneer of the cognitive revolution. They are useful additions to existing models in psychology and AI, allowing for fast, transparent and accurate decisions. In the wild, simplicity and transparency are not necessarily enemies of accuracy.

■ WC-22

Wednesday, 12:30-14:00 - Virtual Room 22

Behaviour in newsvendor and dynamic decision making environments

Stream: Behavioral Operations Management
Invited session
Chair: *Ilkka Leppanen*

1 - Performance in complex dynamic systems: An empirical investigation of global versus local processing style
Manuel Brauch, Andreas Größler

In the extant literature, it is widely documented that the performance of individuals is relatively poor when it comes to decision-making in dynamic systems. Based on this finding, previous research has attempted to identify factors related to decision-making performance. This research suggests that the difficulty to understand dynamic systems can be observed not only in complex, but also in very simple systems. Utilizing such a basic system (the department store task), Fischer & Gonzalez (2016) found that a global as opposed to a local processing style is related to an improved performance and suggest that a global processing style should also be beneficial in a more complex system. Thus, using the beer distribution game, the hypothesis that a global processing style is related to better performance in a complex system is tested in our study. As in the study by Fischer & Gonzalez (2016), global versus local processing style is measured using the Kimchi-Palmer-Figures task. The results indicate that there is no significant relationship between a global versus local processing style and the performance in the beer distribution game. The findings suggest that relationships found in simple systems do not necessarily translate to more complex systems.

2 - Decision making, cognitive reflection, and the overconfident newsvendor
Julian Wiesner, Ivan Dula, Andreas Größler

Previous research on inventory ordering decisions has shown systematic and persistent deviations from the optimum order quantity, for instance in newsvendor problem tasks. This paper investigates the relationship between cognitive reflection and overconfidence bias as factors influencing these ordering decisions. The hypothesis that higher cognitive reflection abilities help individuals to improve the assessment of their abilities and, hence, to achieve higher task performances is tested in an experimental study, employing 60 participants. We find that individuals with higher cognitive reflection abilities show a more valid level of self-assessment and, therefore, exhibit lower overconfidence in their decisions. Results also indicate that overconfidence is related to task outcome measures including average realized profit, average order quantity, and order quantity variance. However, these performance measures are not influenced equally by the three dimensions of overconfidence (overestimation, overplacement, and overprecision). In summary, findings suggest that overconfidence as a decision bias is moderated by individual cognitive reflection abilities and contributes to the biased ordering behaviors observed.

Keywords: Behavioral operations, newsvendor problem, decision making, order bias, cognitive reflection, overconfidence, task performance

3 - Behavioral biases in newsvendor competition: an indirect evolutionary approach
Ilkka Leppanen

Recent literature has shown that behavioral biases can explain non-normative decision making of competing newsvendors. We use an indirect evolutionary approach where players maximize biased utility functions but actual profits determine fitness to study 2 behavioral biases, reference effects based on profit comparisons and overconfidence, in newsvendor competition. We show that both kinds of behavioral biases can be evolutionarily stable and lead to increases in inventory levels from the profit-maximizing equilibrium quantities, in line with experimental findings reported in literature.

■ WC-23
Wednesday, 12:30-14:00 - Virtual Room 23

Expansion Problems in Energy Systems

Stream: Engineering Optimization
Invited session
Chair: *Christine Tawfik*

1 - A hierarchical algorithmic framework for a real-world district heating expansion problem
Jan-Patrick Clarner, Christine Tawfik, Janina Zittel, Thorsten Koch

In the course of the energy transition, district heating systems are evolving to comprise decentralized and regenerative technologies. The underlying investment and operation decisions exhibit combinatorial structures, for which methods from operations research are beneficial. We consider a large-scale mixed integer linear program representing a district heating expansion problem in Berlin with a 25-year time horizon in a four-hour resolution with real data. The model is created by a heat energy provider with a state-of-the-art software tool offering a high degree of flexibility. The solution procedure relies on commercial solvers for which the model size of hundreds of millions of variables and constraints is too large. Therefore, we develop an equivalent modeling framework from which we can extract mathematical substructures. To handle the resulting model, we set up a coarse-to-fine hierarchical framework with three levels. Coarse models are solved to derive variable fixings for fine models. To create coarse models, we relax constraints of the original model and aggregate time steps. The latter means to substitute a time period in the optimization problem by fewer representative days. For this, we use clustering, averaging and scaling methods. To solve the corresponding optimization problems, we combine column generation and rolling horizon techniques. Finally, we perform computational experiments on sample instances to assess the quality of the methods.

2 - Benders decomposition with a second-order cone constrained trust-region for large capacity expansion problems
Leonard Göke, Mario Kendziorski

Continuous capacity expansion models of the energy system analyze how supply of primary energy can shift to renewable energy from wind and solar in the coming decades. Using off-the-shelf solvers limits the temporal and spatial detail dedicated to the fluctuating and location-dependant generation from wind and solar in these models. In particular, the representation of different weather years was found to be important, but difficult to achieve.

To apply Benders decomposition, the capacity expansion problem is split into a top problem determining capacity investment and several sub-problems; one for each combination of historic weather years and periods of capacity expansion considered. Since all subproblems are independent from each other, solving them can be entirely parallelized.

Next, the model is first solved conventionally with a single weather year and a reduced time-series as a heuristic. Afterwards, a trust-region is added to the top problem by limiting the Euclidean distance to the heuristic solution resulting in a single second-order cone constraint. During the subsequent iteration process the trust-region is continuously re-sized and -centred to stabilize convergence of the Benders algorithm.

Preliminary results indicate that the method outperforms off-the-shelf solvers and can substantially increase the level of spatio-temporal detail in capacity expansion models.

3 - A mathematical model for network expansion problem in electricity distribution
Ayşenur Yurtsever, Berna Dengiz, Burcin Cakir Erdener, Ismail Karaoglan

The demand for electricity has seen an ever-growing trend due to fast technological developments and rapidly growing population. This increase in consumption and/or the establishment of new demand points can be considered one of the key challenges that distribution system operators are expected to face in present and future. This means that, in order to provide reliable and continuous power, capacity will need to be regularly extended by an optimal investment plan. This study presents a new mixed-integer mathematical model which is used to solve multi-stage distribution expansion problem with different reliability levels on each consumer. Its goal is to minimize investment, maintenance, production, energy losses and system reliability costs while satisfying the increase in demand. In this study the expected power outage caused by the line interruptions for each demand point is limited. The proposed model is implemented on a 24-bus test system. The numerical results show the good performance of the model.

4 - Planning Incentives for Maximal End-of-horizon Installed Capacity of Renewables
Ezgi Zehra Kadız, Burak Pac

The effect of public incentive policies on renewable energy investments and sectoral growth is estimated through times series and multiple linear regression. Incentive mechanisms considered are purchasing guarantees and direct partial funding. The uncertainties involved in output rate from installed capacity, as well as investor response to incentive policies are modeled as prescribed by the estimation method used.

Yearly budgets determined throughout the planning horizon are scrutinized with probability chance constraints while maximizing end-of-horizon installed capacity for renewable energy by a dynamic scenario based stochastic programming model.

■ WC-24

Wednesday, 12:30-14:00 - Virtual Room 24

DEA applications in education

Stream: Data Envelopment Analysis and Performance Measurement
Invited session
Chair: *Chiara Masci*

1 - ICT as a determinant of inefficiency: An efficiency measurement in education of selected OECD countries
Muhammad Mujiya Ulkhaq, Kristof De Witte, Giorgia Oggioni, Rossana Riccardi

The role of information and communication technologies (ICT) in education is well established. There seems to be a consensus among scholars and practitioners that ICT enables the educational process to be managed efficiently. Regarding the efficiency measurement of educational institutions, there is a large literature examining this issue. However, the role of ICT as a determinant of inefficiency is scarcely addressed. This paper aims to investigate the efficiency of selected 24 OECD countries in terms of education by including ICT as a determinant of inefficiency. Using the OECD PISA data of 2009 to 2018, we used the parametric approach of efficiency measurement, namely, stochastic frontier analysis, to accomplish the objective of the study. Four random components of the stochastic frontier model, i.e., statistical noise, individual heterogeneity, persistent inefficiency, and time-varying inefficiency, were incorporated into the model. This study represents the first attempt of an efficiency analysis in an international comparison by modelling the four-component heteroscedastic model, where the ICT plays as a determinant of the inefficiency. This study is expected to allow more purposeful policy recommendations as well as expand the literature regarding efficiency measurement in education.

2 - Multi-function parallel network hierarchical systems: An application to the higher education
Marios Dominikos Kremantzis, Patrick Beullens, Jonathan Klein

Many organisations are composed of multiple departments connected either in series or in parallel, which may be further decomposed into a number of functions arranged in a hierarchical structure. Several researchers have successfully used appropriate Data Envelopment Analysis (DEA) modelling techniques to assess complex structures. However, to our knowledge, no-one has examined the case of evaluating a parallel (network) structure combined with a hierarchical one. This paper discusses the development of a multi-function parallel system with embedded hierarchical network structures. A linear additive decomposition DEA model and a non-linear multiplicative aggregation DEA model are proposed as alternatives to evaluate the operating performance of such a structure. The system, the sub-systems, and the efficiencies of their internal units, as well as their relationships, are identified. The system efficiency of the additive model is shown to be greater than or equal to that of the multiplicative model. To verify the applicability of our proposed models, we consider a hypothetical example of the evaluation of the performances of several Business Schools across a number of universities.

3 - Efficiency-based funding allocation for universities in Russia
Abalmasova Ekaterina, Tommaso Agasisti

The global trend to increasing the accountability of universities makes governments develop funding mechanisms that incentivize the efficiency of university activities. Nowadays most governments gradually have been shifting from historical and negotiation-based state funding allocation to either activity-based funding or performance-based funding mechanisms. Despite the fact, that both activity-based and performance-based funding mechanisms are based on measures highly related to main activities of universities, there are obvious drawbacks of these mechanisms that makes them work not effective enough or even induce negative externalities. This study proposes an alternative way of existing state funding allocation in Russia. Proposed mechanism is based on efficiency principles when amount of money is determined not with accordance to input-output ratio (efficiency score of a university). Government as a central planner allocates state funding among universities to maximize the total quantity of outputs from all universities. Research strategy contains two steps. First stage is devoted to estimation of the efficiency scores of each university using DEA on actual data. At the second stage government uses multi-objective linear programming to maximize the overall outputs. To sum up, the idea of the paper is to compare how state funding is allocated today and how it might be hypothetically allocated under other conditions and estimate the effect on university performance.

4 - Profiling university students through an innovative semiparametric mixed-effects multinomial model
Chiara Masci, Francesca Ieva, Anna Maria Paganoni

Student dropout is an interesting phenomenon that interests many universities in Italy. When considering efficiency, dropout represents a net waste of resources and Politecnico di Milano detects a dropout rate equal 30%. In the perspective of preventing this phenomenon, we propose a method to classify students standing on their probability of dropping their studies, estimated at the beginning of their academic career. We develop a semiparametric multinomial mixed-effects model, considering the nested structure of students into different engineering degree programs. We classify students into three categories: graduate, early and late dropout. The novel semiparametric approach assumes the random effects of the mixed-effects model to follow a multivariate discrete distribution with an a priori unknown number of support points, that is allowed to differ across response categories. The advantage of this modelling is twofold: the discrete distribution on random effects allows, first, to identify a latent structure at the highest level of the hierarchy, and, second, to model the dependence structure at the highest level of grouping across response categories. The method identifies the student characteristics associated to the dropout probability and clusters degree programs into subpopulations, revealing the internal dynamics of the dropout phenomenon at Politecnico di Milano. Results are compared with the ones obtained by applying a full parametric mixed-effects multinomial model.

■ WC-25

Wednesday, 12:30-14:00 - Virtual Room 25

Multicriteria Group Decision Making

Stream: Group Decision Making
Invited session
Chair: *Raquel González del Pozo*

1 - Aggregation of incomplete rankings in Multiple Criteria Group Decision Making
Grzegorz Miebs, Milosz Kadzinski

Most multiple criteria decision aiding methods that deliver a ranking of alternatives as output are suitable for a single decision-maker. We aim to propose a general framework to apply any of these methods in a group decision-making process. This is attained by implementing an output-oriented perspective, i.e., applying the method separately for each user and aggregating thus obtained outcomes into a compromise one. We focus on partial (incomplete) ranking at both the input and output of the proposed approach. By defining the distance metric between rankings, the considered task becomes an optimization problem. Thus, various metaheuristics, dedicated algorithms, and neural network approaches are suitable to solve it. We consider the utilitarian and egalitarian perspectives oriented toward minimizing an average or a maximal distance from any input ranking. In addition, we account for the weights associated with the input rankings.

2 - A Goal Programming model to guide consensus in conservation decision-making
Monica de Castro-Pardo, Joao C. Azevedo

In this study we propose a Goal Programming model that provides a consensual aggregated solution when participants of different groups assess the same criteria, generating information regarding groups on which efforts in negotiation processes should be focused on and developing sensitivity analysis to quantify variations in conflicts when the relative contribution of each criteria changes. A dataset of a case study in the Meseta Ibérica Biosphere Reserve (Portugal-Spain) was used to test and validate the model. Fifty people belonging to four groups (Scientists, Government, Farmers and Businesspersons) assessed 20 management objectives in four dimensions: Conservation, Logistical support, Development and Governance. The results showed the highest conflicts to be found for Fauna and Flora, Education and Guarantees objectives while the most conflictive groups were Scientists and Farmers. The proposed model reduced the global and intergroup conflicts associated to the same objectives on near 20% and 56%, respectively, modelling the weights assigned to each objective in each dimension in order to achieve the least conflictive solutions. This model can be a useful tool to improve complex decision-making processes in conservation areas with strong conflicts between stakeholders, such as transboundary Biosphere Reserves.

3 - A group decision-making procedure with heterogeneous experts and qualitative assessments
Raquel González del Pozo, José Luis García-Lapresta

Some decision making problems require the evaluation of a set of alternatives by a group of experts through ordered qualitative scales formed by linguistic terms. Usually, these ordered qualitative scales are considered to be uniform, in the sense that the proximities between consecutive terms are identical. However, sometimes, common sense, cultural differences or even the individual's personality can cause that the scales can be considered as non-uniform. To deal with non-uniform ordered qualitative scales, we use ordinal proximity measures which collect information about how individuals perceive the proximities between the terms of scales.

In this contribution, we present a decision-making procedure to rank alternatives evaluated by a group of experts with different expertise. The procedure manages two different ordered qualitative scales: one to evaluate the knowledge of the experts and another one to assess the alternatives by the experts. The procedure assigns numerical scores to the linguistic terms of the ordered qualitative scales taking into account the ordinal proximities between the linguistic terms. Then, all the information is aggregated through a weighted mean and a global score is generated for each alternative. The proposed procedure is extended to the multi-criteria context.

4 - Data visualization for reaching consensus in the Multi-Actor Multi-Criteria Analysis
He Huang, Yves De Smet, Cathy Macharis

The multi-actor multi-criteria analysis (MAMCA) has successfully supported the decision-making process in different areas especially in mobility and transportation. The distinctive feature of MAMCA is the involvement of multiple stakeholders, which reflects their different points of view, leading to a proper solution satisfying their interests. A main difficulty during the evaluation step is the conflict of interests of different groups of stakeholders leading most of the time to distinct preferred solutions. To reach a consensus in MAMCA, a model based on inverse mixed-integer linear optimization (MILP) and previously developed in the context of PROMETHEE methods is applied. By presenting results as Pareto optimal solutions, a subset of compromise solutions can be selected and discussed. However, this representation is not always easily interpretable by real decision-makers. In this work, we propose to further extend this approach by developing additional visual tools and indicators in order to facilitate the understanding of the MILP results. This is illustrated in the context of PROMETHEE methods.

■ WC-26

Wednesday, 12:30-14:00 - Virtual Room 26

Recent advances on preconditioning for PDE-Constrained optimization

Stream: Nonlinear Optimization
Invited session
Chair: *Margherita Porcelli*

1 - Deferred correction, Newton-Krylov methods, and preconditioning for time-dependent PDE-constrained optimization
John Pearson

In this talk, we consider the solution of first-order optimality conditions arising from time-dependent PDE-constrained optimization problems. A key challenge when solving such systems is the choice of time discretization: on one hand, lower-order time-stepping schemes generally require the solution of huge-scale linear systems to obtain accurate solutions; on the other hand, higher-order schemes are not amenable to many widely-used preconditioners for PDE-constrained optimization. Here, we discuss two potential remedies to this challenge for a number of problems: (i) a deferred correction approach to successively improve the order of convergence of time-stepping schemes, while only requiring much coarser time discretizations as opposed to more standard approaches; (ii) a method for nonlinear problems that involves a spectral-in-time approximation of the residual, alongside a Newton-Krylov method to drive the residual to zero. Both deferred correction and Newton-Krylov methods are accelerated by preconditioners, which allow us to solve such problems to high accuracy in modest CPU time. We summarise each approach along with our recommended preconditioning strategies, and demonstrate the potency of both methods through a range of numerical examples.

This is joint work with Stefan Güttel (University of Manchester).

2 - Preconditioners for saddle point weak-constraint 4D-Var with correlated observation errors
Jemima Tabeart, John Pearson

Data assimilation algorithms for numerical weather prediction are increasingly high dimensional, and complicated with the widespread use of correlated observation error covariance matrices. Fast convergence is essential, making the saddle point formulation of weak-constraint 4D-Var desirable due to its potential for parallelization. We present new preconditioners which better approximate the model and observation error terms and have additional parallelizable structure. Previous work has found that correlated observation errors, which are often neglected by standard preconditioners, can lead to ill-conditioned data assimilation problems. We show for the heat equation that accounting for observation error correlations in the preconditioners is necessary for fast convergence. Our new approach results in faster convergence in serial than standard approaches, and can be easily adapted to exploit parallel computer architectures.

3 - A New Preconditioning Approach for an Interior Point–Proximal Method of Multipliers for Linear and Convex Quadratic Programming
Luca Bergamaschi

We address the efficient numerical solution of linear and quadratic programming problems, often of large scale. With this aim, we devise an infeasible interior point method, blended with the proximal method of multipliers, which in turn results in a primal-dual regularized interior point method. Application of this method gives rise to a sequence of increasingly ill-conditioned linear systems which cannot always be solved by factorization methods, due to memory and CPU time restrictions. We propose a novel preconditioning strategy which is based on a suitable sparsification of the normal equations matrix in the linear case, and also constitutes the foundation of a block-diagonal preconditioner to accelerate MINRES for linear systems arising from the solution of general quadratic programming problems. Numerical results for a range of test problems demonstrate the robustness of the proposed preconditioning strategy, together with its ability to solve linear systems of very large dimension.

4 - A low-rank matrix equation method for solving PDE-constrained optimization
Alexandra Buenger, Valeria Simoncini, Martin Stoll

Discretizing a PDE-constrained optimization problem and using a Lagrangian approach result in a large-scale saddle-point system, which is challenging to solve, and acquiring a full space-time solution is often infeasible. We present a new framework to efficiently compute a low-rank approximation to the solution by reformulating the KKT system into a Sylvester-like matrix equation. We use a rational Krylov subspace method to subsequently project the problem and solve a reduced system, making our framework time- and memory-efficient.

■ WC-27
Wednesday, 12:30-14:00 - Virtual Room 27

OR in RNA modeling

Stream: OR in Computational Biology, Bioinformatics and Medicine
Invited session
Chair: *Maciej Antczak*

1 - Graph algorithms to identify recurrent RNA 3D motifs
Carlos Oliver, Jerome Waldispuhl, Vladimir Reinharz

RNAs are versatile biomolecules involved in a broad range of biological functions. They often acquire these functions through highly modular 3D architectures. A complete characterization and classification of evolutionary conserved structural (sub-)units (a.k.a. RNA 3D motifs) is essential to reveal the fundamental features and decipher the evolution of the RNA structural code. It is also a milestone toward accurate RNA 3D structure prediction tools. Here, I describe a series of algorithms to automatically identify conserved RNA 3D motifs from experimental 3D structures. We represent RNA structures as a graph of base interactions and aim to find occurrences of similar subgraphs. First, I describe CaRNAval, a systematic pairwise comparison of all available 3D structures using heuristics and combinatorial algorithms to retrieve identical sub-graphs. It enables us to build a catalog of recurrent motifs that includes long-range non-nested interactions, an essential feature to stabilize the 3D architecture of large RNA molecules. Next, I expand the scope of our search with VeRNAl, a computational framework using graph representation learning and clustering techniques to retrieve similar (but not necessarily identical) sub-graphs. This approach is faster and more flexible, and enables us to retrieve and expand known classes of motifs, but also identify new ones. Joint work with V. Reinharz, A. Soulé, C. Oliver, V. Mallet, P. Philippopoulos, A. Denise, E. Westhof, W. Hamilton.

2 - An algorithm to detect entanglements in 3D RNA models
Marta Szachniuk, Mariusz Popenda, Tomasz Żok, Maciej Antczak, Joanna Sarzynska

The presentation addresses a new problem defined in the bioinformatics of RNA structures. Three-dimensional models of computer-generated RNA structures may include entanglements that do not occur in nature. They are observed when two disjoint elements of the structure - loops or open single-stranded fragments - puncture each other. An analysis of a set of over 1,000 predictions available within RNA-Puzzles resources shows that the problem affects about 20% of the models. Here we present the first algorithm that can automatically identify such cases. We propose a new classification of entanglements based on their topology and the contributing structure elements. It distinguishes two superior classes, interlaces and lassos, and subclasses characterized by element types. We show the distribution of entanglements of different types in the analyzed set of RNA 3D models. Partial support for this research is provided by the National Science Centre, Poland [grants 2016/23/B/ST6/03931, 2019/35/B/ST6/03074].

3 - New algorithms for RNA pseudoknot order assignment
Maciej Antczak, Tomasz Żok, Jan Badura, Mariusz Popenda, Marta Szachniuk

RNAs are often folded into complex 3D structures. The longer the sequence is, fascinating motifs called pseudoknots are more likely observed. Pseudoknots are regular Watson-Crick base pairs formed between sequentially distant nucleotides that would unwind during melting just as any other base pair. These motifs are evolutionarily conserved, therefore are responsible for the stabilization of RNA structure. Due to topological diversity, their detection and classification are still a challenge. In literature, a few ways of pseudoknots classification have been proposed, e.g., by type, family, or by topological genus. We have also introduced a pseudoknot order that measures the topological complexity of the pseudoknotted RNA. It is defined as the minimum number of base pairs set decompositions, aimed to obtain the unknotted RNA structure. Unfortunately, it is not trivial to unambiguously identify pseudoknots and determine their orders in an RNA structure. Here, we propose a specialized heuristic operating on a novel graph coloring-based model, and an alternative integer programming algorithm. The performance of the proposed algorithms was assessed within the context of state-of-the-art algorithms solving the problem in question on a representative non-redundant RNA 3D structures set. Partial support for this research is provided by the National Science Centre, Poland [grants 2016/23/B/ST6/03931, 2019/35/B/ST6/03074].

4 - Graph-based approach for quadruplex analysis
Tomasz Żok, Mariusz Popenda, Marta Szachniuk

Biomolecules play vital roles in the cells of living organisms and viruses. These roles depend on the fold, i.e., the molecules' 3D shape. For many years structural bioinformaticians have been striving to provide reliable models and methods to understand this structure-function relation. Yet as experimentalists discover novel folds, the need for updated models is growing. Here, we present a graph-based approach to describe and thus understand a relatively new and incredibly complex 3D structural motif of a quadruplex. Quadruplexes are four-stranded nucleic acid motifs, usually forming in G-rich regions of the genome. They are abundant in all domains of life and serve many biological roles. Several studies link quadruplexes' presence or lack thereof with certain diseases. The available, experimentally solved 3D structures of quadruplexes demonstrate their incredible complexity and a multitude of possible spatial configurations. Therefore, it is crucial to classify and organize this information with the ultimate goal of fully understanding the quadruplexes' behavior. Our graph-based approach processes only the basic information retrieved from the 3D coordinates. In two stages, we reconstruct the building blocks of the quadruplexes and their internal arrangement. The resulting model of the quadruplex allows us to classify it and calculate a set of quantitative parameters. It is the first fully automatic method to provide this level of detail starting from 3D coordinates only.

■ WC-28

Wednesday, 12:30-14:00 - Virtual Room 28

The Role of Mathematical Optimization in Data Science V

Stream: Mathematical Optimization and Data Science
Invited session
Chair: *Vanesa Guerrero*

1 - Sheepdog Algorithm: A new bio-inspired approach for feature selection.
Shubbham Gupta, Paula Carroll, Michael Fop

A feature is a measurable property of interest in the model construction problem. Over the past years, the domain of features in machine learning applications have grown from tens to thousands of features used. In today's world, feature selection is a crucial task for faster and effective results. Feature selection is picking a subset of features from the whole set, leading to dimensionality reduction for efficient tasks. Many approaches have been proposed, including statistical and metaheuristics approaches. One of those approaches is bio-inspired algorithms. These metaheuristic algorithms are inspired by different biological phenomena and approximate the solution in reasonable computational time

In our work, a new algorithm, namely SheepDog Algorithm (SDA), is proposed as a wrapper method for feature selection. It mimics a sheepdog's behaviour and controls the herding of a flock of sheep on farms. It is an example of one individual causing many unwilling individuals to move in the same direction. Every sheep denotes a subset of features, and they are moved in an encoded map defined by the count of features in the subset and the accuracy of the selected features. The algorithm's task is to move the flock towards a region of low feature count and high accuracy. The feature selection algorithm is developed using this idea, and the performance of the same is recorded and compared with other existing algorithms.

2 - Linear regression with probabilistic linked data
Sandra Benítez-Peña, Rafael Blanquero, Emilio Carrizosa, Pepa Ramírez-Cobo

Data linkage is a process that can be used for joining together data sets that contain information of the same entities, but lack of unique identification codes. Although real data come from an exact matching, the procedure of data merging does not need to be exact: a single entity can be joined to two or more if they are similar enough. In this talk, we present a novel Non-Linear Programming model that integrates, in a single step, the task of obtaining a probabilistic data linkage and also performs linear regression using such matched data. Numerical results are presented for both simulated and real data sets, demonstrating the power of our methodology, particularly when good initial solutions are provided.

3 - Fitting smooth curves satisfying sign, growth and curvature requirements by means of P-splines and Semidefinite Optimization.
Vanesa Guerrero, Manuel Navarro García, Maria Durban

In an era when the decision-making process is often based on the analysis of complex and evolving data, it is crucial to have systems which allow to incorporate human knowledge and provide valuable support to the decider. In this work, statistical modelling and mathematical optimization paradigms merge to address the problem of estimating smooth curves which verify structural properties, both in the observed domain in which data have been gathered and outwards. We assume that the smooth curve to be estimated is defined through a reduced-rank basis (B−splines) and fitted via a penalized splines approach (P−splines). In order to incorporate requirements about the sign, monotonicity and curvature in the fitting procedure, a semidefinite programming approach is developed which, for the first time, successfully conveys out-of-range constrained forecasting.

This approach is successfully applied to simulated and demographic data, as well as to data arising in the context of the COVID-19 pandemic. If a smooth curve is fitted using an unconstrained approach, misleading results might be depicted. That is the case of, for instance, curves depicting a negative number of cases in certain time periods. Furthermore, forecasting the evolution of the pandemic under a different set of constrained scenarios, such as having an estimated growth rate, is also possible using the approach developed in this work.

4 - On semidefinite optimization approaches to estimate smooth surfaces subject to shape constraints using P-splines
Manuel Navarro García, Vanesa Guerrero, Maria Durban

In this talk, we address the problem of estimating smooth m-dimensional surfaces in a regression problem for data lying on large grids, and where the fit of the data needs to satisfy shape constraints such as non-negativity or monotonicity in a certain direction. There are many situations which demand for estimating procedures that are able to incorporate desirable properties to, for instance, enhance interpretability and avoid misleading out-of-range predictions. Many examples arise in medicine, demography or the environment.

This work is a non-trivial extension of the one-dimensional shape constrained framework developed by Navarro-García, Guerrero and Durban (2020) to the m-dimensional case. Our aim is thus to estimate a smooth surface, which is constructed from the tensor products of B-splines basis and fitted using the P-splines approach (Eilers and Marx, 1996), so that certain shape constraints such as non-negativity or monotonicity are satisfied. These requirements are imposed using an approach based on semidefinite programming which imposes the constraints over a finite set of curves that belong to the surface. Our methodology is able to deal with constrained smoothing and constrained out-of-range prediction.

■ WC-29

Wednesday, 12:30-14:00 - Virtual Room 29

Autonomous vehicles, drones and robots in routing problems

Stream: Routing, Logistics, Location and Freight Transportation
Invited session
Chair: *Stefan Schaudt*

1 - Shuttle routing in automated parking lots
Alon Bloch, Mor Kaspi

In recent years, lack of parking spaces has become a major concern in dense cities. To overcome this issue, several companies are offering Automated Parking Lots (APL), which enable higher land resources utilization then in conventional parking lots. In an APL, users park their cars in designated entry/exit rooms and later on pick them up from these rooms. The movement of the cars to/from parking spots is performed automatically by robots. This study focuses on a particular APL design in which cars are carried by shuttles, moving on a single horizontal rail in each floor and moving vertically using two elevators located at both ends of the rails. This setting introduces several operational challenges, including, parking spot allocation, task allocation to shuttles and shuttle routing, which should consider shuttle conflicts to avoid system deadlocks. To reduce potential conflicts, several companies apply a circular routing policy. Namely, one elevator is used to take the shuttles up, while the other takes them down. However, under this policy the elevators become the bottleneck as their utilization rate is bounded up to 50%. We approximate the system by a Markovian model, and use it to demonstrate that less conservative policies may enable the system to serve up to twice as many users. Furthermore, we present heuristic routing methods the are shown to perform better on real world scenarios obtained from an automated parking lot manufacturer.

2 - The Vehicle Routing Problem with Drone Stations
Konstantin Kloster, Mahdi Moeini, Daniele Vigo, Oliver Wendt

We study the Vehicle Routing Problem with Drone Stations (VRP-DS). In the VRP-DS, a depot, a set of customers, and a set of drone stations are given. A drone station is a parcel storage place equipped with autonomous drones (or robots). Starting from the depot, the trucks deliver parcels to the customers and return to the depot by the end of their tour. In addition, within their tours, the trucks can also visit (and activate) a limited number of drone stations. Through an activation process, a truck visits a drone station and hands over packages. Then, a set of drones, located at that drone station, can start serving customers within a given range and by round trips, i.e., starting from the drone station, visiting a customer location (to deliver a parcel), and ending at the same drone station. After each delivery, the drones are recharged (instantly) at the drone station and can start a next delivery, if required. The objective of the VRP-DS is to serve all customers by either trucks or drones while minimizing the makespan. We formulate the VRP-DS as a mixed integer linear program (MILP), to be solved by any standard MILP solver, and present two matheuristic algorithms for addressing large-scale instances. According to the results of our computational experiments, the use of drones and drone stations can significantly improve the makespan. Furthermore, the numerical results show that our algorithms provide high-quality solutions in short computation time.

3 - Energy-constrained Traveling Salesman Problem with Multiple Drones
Bahare Mahmoudi, Kourosh Eshghi

One of the most remarkable developments in transportation in recent years refers to the potential use of drones to transport packages. In this work, a Ground Vehicle (GV) equipped with multiple drones is considered to serve the demand of all customers collaboratively. The GV route starts from the depot, and after serving a subset of customers, returns to the depot. The drones may be launched or retrieved at the customers' locations by the GV. GV and drones need to be synchronized at the recovery locations. It is assumed that the drones are allowed to serve multiple customers on each trip. When the drone reaches the demand point, the eligible customer can be recognized by identification mechanisms such as scanning images of customers or scanning of QR code. Each drone may have a multi-trip during the planning horizon. At the end of each trip, the drone comes back to the GV to swap its battery. The drone energy consumption in different phases of each trip is considered in the model. This leads to more realistic modeling, which reduces the potential risk of running out of drone battery energy before returning to its recovery location. The problem aims to minimize the makespan. We formulate the problem as a mixed-integer linear program. Then a heuristic algorithm is presented for solving large-scale instances due to this fact that the problem is NP-hard. Extensive numerical testing revealed that this approach is capable of effectively solving generated instances.

4 - Mission and Flight Planning for an Inhomogeneous Fleet of Unmanned Aerial Vehicles
Johannes Schmidt, Armin Fügenschuh

Operating Unmanned Aerial Vehicles (UAVs) got a fast evolving field in the last decades due to their great opportunity for autonomous work. With the increasing number of potential applications, also the need of detailed planning methods arises. Thus, we consider the mission and flight planning problem for an inhomogeneous fleet of UAVs. Therein, the mission planning problem of assigning targets to the particular UAVs and the flight planning problem of finding optimal flight trajectories between a given set of waypoints are combined and tackled at the same time. An existing mixed-integer non-linear model is extended by a multi-level time-grid approach to compute smooth trajectories. The participating UAVs have detailed physics of flight, including mass-dependent technical parameters and altitude-dependent operating range, while convex-shaped restricted airspaces and wind zones describe environmental restrictions to the considered mission area. Furthermore, the resulting trajectories have to be collision-free to ensure the safe operation of the considered fleet. By several linearization techniques, we derive a mixed-integer linear model and demonstrate its applicability to GUROBI as a state-of-the-art numerical solver for different scenarios. Finally, we study the collision avoidance on a class of benchmark instances and prove an upper bound on their objective value.

WC-30

Wednesday, 12:30-14:00 - Virtual Room 30

Recent development in Mixed Integer Linear Programming

Stream: Mixed Integer Linear Programming
Invited session
Chair: *Matthias Walter*

1 - Exploiting Subgroup Structures in Symmetry Handling
Christopher Hojny, Fabian Wegscheider

Branch-and-bound is a powerful method for solving mixed-integer programs. If symmetries are presented, however, this method is typically slow because it will explore symmetric parts of the search space, which is highly undesirable because symmetric parts cannot provide new information about improving optimal solutions. For this reason, symmetry handling inequalities have been developed that cut off solutions that are not lexicographically maximal in their symmetry class w.r.t. the problem's symmetry group. If the symmetry group is (isomorphic to) a symmetric group, these inequalities are in general very strong; for arbitrary groups, however, the inequalities can be rather weak.

In this presentation, we will discuss how strong symmetry handling inequalities for symmetric groups can be exploited if the integer program's full symmetry group is not a symmetric group. On the one hand, we will show how symmetric subgroups can efficiently be detected. On the other hand, we will discuss means to leverage the strong symmetry handling effect for symmetric subgroups to the problem's full symmetry group. Numerical experiments using the solver SCIP show the effectiveness of this approach.

2 - Advances in Exact Rational Mixed Integer Programming
Leon Eifler, Ambros Gleixner

The state of the art framework for roundoff-error-free solving of general mixed integer programs over the rational numbers is to this day the hybrid-precision algorithm introduced by Cook, Koch, Steffy, and Wolter in 2013.

We present a revision of this framework coupled with the extensions of symbolic presolving, a repair step for solutions from floating-point heuristics, and a faster rational LP solver based on LP iterative refinement.

We analyze results on the improved performance and give insights into the computational behavior of the new algorithmic components.

3 - A Computational Study of Perspective Cuts
Ksenia Bestuzheva, Ambros Gleixner, Stefan Vigerske

Semi-continuous variables are a useful tool for modeling switching between "on" and "off" states. These variables are either fixed to a constant value or constrained to be within some interval, depending on the value of a binary indicator variable. This talk focuses on feasible sets defined by a nonlinear constraint on semi-continuous variables. Perspective cuts are outer approximations of the convex hull of such a set. We present a method for constructing generalized perspective cuts for nonconvex as well as convex constraints and show that in the convex case, the cuts are equivalent to the classical perspective cuts. We implement perspective cuts within the general-purpose MINLP solver SCIP and conduct a computational study on the instances from MINLPLib. The results of the study show that enabling perspective cuts for convex constraints improves the running time of the solver, and enabling perspective cuts for nonconvex constraints improves root node dual bounds and reduces branch-and-bound tree sizes, but does not have a significant impact on the running time.

4 - Dynamic Partition Search - A Primal Heuristic exploiting Decomposition Information
Katrin Halbig, Dieter Weninger

Most real world mixed-integer linear problems have special structures which can be exploited in MIP solvers. We take a closer look at problems that can be decomposed into loosely coupled blocks and show how this decomposition information can be used. The main focus is on a novel decomposition heuristic called dynamic partition search. This construction heuristic splits a MIP according to a given decomposition into independent subproblems and searches for a feasible partition of the right-hand side on the blocks. This technique was implemented in SCIP and computational results are presented.

5 - Face Dimensions of General-Purpose Cutting Planes for Mixed-Integer Linear Programs
Matthias Walter

Cutting planes are a key ingredient to successfully solve mixed-integer linear programs. For specific problems, their strength is often theoretically assessed by showing that they are facet-defining for the corresponding mixed-integer hull. In this paper we experimentally investigate the dimensions of faces induced by general-purpose cutting planes generated by a state-of-the-art solver. Therefore, we relate the dimension of each cutting plane to its impact in a branch-and-bound algorithm.

■ WC-31

Wednesday, 12:30-14:00 - Virtual Room 31

Influence maximization in (social) networks

Stream: Network Optimization
Invited session
Chair: *Michael Kahr*

1 - Two-Level Influence Maximization Problem under Deterministic Linear Threshold Model
Dilek Gunnec, Doruk Eski, Mihail Duscu

Data-driven decision-making strategies can make online marketing more efficient and help companies reach a larger number of customers using limited resources. In this respect, the Influence Maximization Problem searches for a certain number of influential individuals on a social network so that the information/product spread initiated from such individuals is maximized. We introduce a novel problem, the Two-Level Influence Maximization Problem, which allows influencing neighbors without eventually adopting the product. To solve this problem, we develop a greedy algorithm where node gains are limited to a specific number of neighbor parameters and a simulated annealing-based metaheuristic with a tabu strategy that exploits the problem-specific neighborhood moves. The computational results on simulated and real social networks show that our heuristics can provide high-quality solutions.

2 - Fairness in Influence Maximization through Randomization
Hugo Gilbert, Ruben Becker, Gianlorenzo D'Angelo, Sajjad Ghobadi

The influence maximization paradigm has been used by researchers in various fields in order to study how information spreads in social networks. While previously the attention was mostly on efficiency, more recently fairness issues have been taken into account in this scope. In this presentation, we propose to use randomization as a means for achieving fairness. While this general idea is not new, it has not been applied in the area of information spread in networks.

Similar to previous works like Fish et al. (WWW '19) and Tsang et al. (IJCAI '19), we study group fairness in the influence maximization problem. More formally, agents of the social network belong to groups, and we aim to ensure that each group receives her fair share of information. In this presentation, we ensure fairness by using a maximin criterion. By allowing randomized solutions, we introduce two different variants of this problem. While the original deterministic maximin problem has been shown to be inapproximable, interestingly, we show that both probabilistic variants permit approximation algorithms with a constant multiplicative factor plus an additive arbitrarily small error due to the simulation of the information spread. Moreover, we provide an experimental study to compare the achieved fairness values to existing methods and which confirms that studying fairness via randomization is a worthwhile direction.

3 - Multinomial logit models for competitive influence maximization
Michael Kahr, Markus Leitner, Ivana Ljubic

A frequently studied problem in the context of digital marketing for online social networks is the influence maximization problem that seeks for an initial seed set of influencers that trigger an information propagation cascade (in terms of message-forwarding) of expected maximum impact. The studied problems typically neglect that the probability that individuals only view content without forwarding it is much higher than the probability that they forward content. We argue that more natural objectives include maximizing: (a) the organic reach or (b) total impressions, or, (c) the expected patronage of the influence spreading entity. To model the latter variant, we propose a new mathematical model that takes into account the individual's resistance to the delivered content and uses a multinomial choice model to model customer behavior. Our model can be easily transformed to account for all of the aforementioned objectives. These models are also geared to a competitive setting in which the seed set of a competitor is already known and contains the problem variants for a single influence spreading entity as special cases. In a computational study based on newly obtained network graphs from Twitter (and from the literature) we show that one can face up to 80% losses in terms of organic reach and total impressions and the expected patronage, respectively, if the classical message-forwarding maximization is used. The performance of our algorithms is compared the performance.

■ WC-32

Wednesday, 12:30-14:00 - Virtual Room 32

Urban and Territorial Planning in MCDA 4

Stream: Multiple Criteria Decision Analysis
Invited session
Chair: *Marta Bottero*

1 - Comparative urban resilience assessment among Latvian cities through a TOPSIS method
Giulia Datola, Maksims Feofilovs, Francesco Romagnoli

The concept of urban resilience is one of the main pillars of the current urban agenda. Cities are facing the challenge of enhancing, improving and maintaining their resilience, to deal with external and internal stresses appearing as hazards. Therefore, the assessment of urban resilience is becoming essential to support the definition of strategies, policy, and actions within this perspective. However, few of the proposed approaches assess urban resilience according to its multidimensional nature. Therefore, this paper offers a measurement approach based on the construction of a composite index, that involves five resilience dimensions society , economy, environment, infrastructure and governance. Within the defined approach a multi-criteria method known as TOPSIS is applied to assess the urban resilience of different Latvian cities. Moreover, a multidisciplinary panel of experts' is engaged in weighting of considered indicators for a multi-perspective evaluation. The final aim is to rank the selected municipalities according to their urban resilience level, evaluated in a multidimensional perspective. The proposed methodology allows assessing the effects of different spatial scales, creating the background and identifying weaknesses and lacks within the urban resilience. Thus, this method can be considered as useful tool to identify which are the key elements and dimensions on which intervene to enhance, maintain and improve the urban resilience performance of different cit

2 - Strategic programming in the post seismic reconstruction process. A dynamic decision making model
Salvatore Giuffrida, Maria Rosa Trovato, Vittoria Ventura, Chiara Circo

The contribution presents the case study of the decision-making process implemented to support the post-earthquake reconstruction time schedule of the old town of Fossa (Italy), a municipality in the Abruzzo seismic crater hit by the 2009 earthquake. This programming tool identifies the areas of the urban fabric to which the funding disbursed over the six-year period must be allocated, thus involving complex preference functions and different decision-making levels that concern technical, organisational, administrative, economic and financial aspects, which can be related the significance and multiplicity of the values involved. The problem of evaluating the best space-time allocation of funding for reconstruction involves two scales, the building one and the urban one. On the building scale, a time schedule based on the MAVT provides a ranking of the building aggregates (elementary units of intervention) with reference to the attributes that define their economic, functional, social and urban planning profile. At the urban scale, an extension of the previous model transforms the MAVT into an adaptive model capable of representing the way in which the structure of preferences changes as the reconstruction proceeds, thus adapting the value functions from year to year. This extension supports ongoing budget rescheduling and reallocation.

3 - A Spatial Multi-Criteria Decision Analysis for a choice problem in infrastructure planning
Giuliano Poli, Maria Somma, Maria Cerreta

Solving discrete choice problems with Spatial Multi-Criteria Decision Analysis (S-MCDA) has meant providing Decision Makers with powerful, complete, and engaging tools to support suitable infrastructure planning for a long time. Whether, on the one hand, drawbacks of new routes were observed by environmental scientists in terms of habitat fragmentation, noise, pollution, and safety, on the other hand, a coherent transportation system can be critical to connecting people and goods in economic and social terms. The landscape is a fragile system to be evaluated by diverse perspectives, taking care of their multidimensional characters. The Landscape Characters Assessment (LCA) allows roads to be integrated within the landscape system following more inclusive criteria - conceived as a common standard of judgments for the evaluation - and metrics, i.e. complexity, naturalness, coherence, disturbance, and openness. A choice problem about the alignment of a new road in the Abruzzo Region (Italy) was structured and faced through a methodological approach in which S-MCDA allowed two spatial alternatives to be evaluated, including a plural perspective according to LCA principles.

References Malczewski, J.; Rinner, C. (2015). Multicriteria Decision Analysis in Geographic Information Science. Springer, Berlin. Jankowski, P. Et al. (2001). Map-centred exploratory approach to multiple criteria spatial decision making. Int. j. Geographical Information Science, 15(2), 101-127.

■ WC-33

Wednesday, 12:30-14:00 - Virtual Room 33

Covid-19: Regimes, Contagion, Integration-

Stream: New challenges for financial modelling
Invited session
Chair: *Alejandra Cabello*

1 - Modelling Oil Pricing Across Different Regimes: A Neural Network Methodology
Anastasios Malliaris, Mary Malliaris

The global financial crisis of 2007-2009 caused major economic disturbances in the oil market. In this paper we consider five variables describing the microeconomics of supply of, and demand for oil and evaluate their importance before, during and after the global financial crisis. We consider five dissimilar regimes during the period of January 1986 to the end of 2017: two regimes prior to the global financial crisis, the regime during the crisis and two regimes after the crisis. The main hypothesis tested is that oil fundamentals of supply and demand remain important even as the five regimes are dissimilar. We build five boosted and over-fitted neural networks to capture the exact relationships between spot oil prices and oil data related to those prices. This analysis shows that, while the inputs into an accurate neural network can remain the same, the impact of each variable can change considerably during different regimes. We find that shifts in impacts of the various inputs are great enough to support the hypothesis that there are important structural breaks between periods.

2 - Stock exchange efficiency and convergence: International evidence
Ephraim Clark, Zhuo Qiao

Abstract to add

3 - Covid19 and Financial Contagion among International Stock Markets Volatility: MS-AR and Scalar and Diagonal BEKK-GARCH analyses
Miriam Sosa, Edgaro Ortiz, Alejandra Cabello

Abstract to be added

4 - Risk Evaluation of Liabilities by Using a Regime-Switching Interest Rate Model and Its Application to the Non-Maturity Deposits
Yukio Muromachi

We propose a stochastic interest rate model with a regime-switching property in order to evaluate the risk of various kinds of interest-rate sensitive liabilities synthetically. This is consistent with the recent policy, in the financial risk management, that there exist some stressed regimes. In our model, parameters included in the short rate process depend on a latent state, which transits between finite regimes with a Markovian property. A Monte Carlo simulation is used to generate many sample paths of the future short rates, and based on them, the interest rate risk is evaluated numerically. Since the term structures of interest rates in future are derived by using the no-arbitrage pricing method on each sample path, interest rates with various maturities can be used for modeling risks. Numerical examples show that the future interest rates do not decrease deeply to negative, rather behave as if they had a lower limit, and that they keep their present trends, while that there exists a small probability under which the future interest rates increase extremely. Applying of our model to the non-maturity deposits, we show that the present trend of the deposits volume is preserved, while that the drastic decrease happens with a small probability. More reasonable results will be obtained if the regime-dependence of the interest-rate sensitivities are also considered.

■ WC-34

Wednesday, 12:30-14:00 - Virtual Room 34

Vehicle Routing and Scheduling

Stream: Combinatorial Optimization
Invited session
Chair: *Konstantinos G. Zografos*

1 - An Integer Programming Time-Space-Battery Level Model For Locating Fast Chargers in One-way Electric Carsharing Systems
Seyma Bekli, Burak Boyaci, Konstantinos G. Zografos

Carsharing is a car rental system in which users pay on hourly or distance basis. In round-trip systems, the users should return the vehicles to the origin station whereas in one-way systems (OWS) the users can return vehicles to any station in the system. In OWS the operations are complicated because of the unbalanced demand distribution. OWS companies often hire staff to relocate vehicles to meet the demand. These systems become more challenging when the fleet is comprised of electric vehicles (EV). It takes 8 hours to fully charge the vehicles with conventional chargers. With new fast chargers, the battery of a vehicle can be fully charged in 30 minutes. We propose an integer programming model to find the locations of the fast chargers to be implemented in a OWS with EVs while considering relocation activities. This model is a time-space-battery level network model which allows vehicles to move with sufficient battery level. As the number of stations increases, the number of relocation variables created increases polynomially making the model intractable. We propose two heuristic approaches based on relocation reduction and clustering. We tested the proposed models/algorithms on real-life instances taken from a OWS with EVs based in Nice, France. The computational results indicate that over 15% profit increase can be made via optimally locating fast chargers. It is observed that the number of served trips and vehicle utilization is increased by 30% and 25%, respectively

2 - A two-stage Mixed-Integer Linear Programming model for the fair and efficient allocation and distribution of disaster relief supplies
Qorib Munajat, Konstantinos G. Zografos, Juliana Sutanto

In this talk we are presenting a two-stage Mixed Integer Linear Programming (MILP) model for optimizing disaster relief supply distribution decisions. In the first stage, we formulate the disaster relief supply allocation problem as a bi-objective network flow model that considers simultaneously fairness and efficiency objectives. The solution of the first stage provides the amount of disaster relief supplies that should be allocated to all demand points. In the second stage we use a multi-echelon, multi-commodity, multi-modal, capacitated vehicle routing and scheduling model with split deliveries and cross-docking, to distribute the allocated disaster relief supplies to demand points. A construction heuristic is used to reduce the computational time for the second stage model. We are reporting results from the application of the proposed modelling and solution framework to realistic problem size instances using historical disaster relief demand data from Indonesia.

3 - Near Optimal Solutions for the Green Vehicle Routing Problem with Capacitated Alternative Fuel Stations
Ornella Pisacane, Maurizio Bruglieri, Daniele Ferone, Paola Festa

Due to the recent worries about the environment and the clime, the use of Alternative Fuel Vehicles (AFVs) is increasingly encouraged instead of conventional vehicles. However, the AFVs have a limited driving range and for this reason, they may require being refueled at the Alternative Fuel Stations (AFSs) also more than once in their trips. Both this limit and a not widespread distribution of the AFSs on the territory lead to the need of planning in advance the routes of the AFVs in order to prevent them from remaining without the sufficient fuel to reach the closest station or to return to the depot. The Green Vehicle Routing Problem (G-VRP) aims at routing a fleet of AFVs minimizing the total travel distance and possibly including stops at AFSs. Each AFV starts from a common depot and returns to it within a maximum duration, serving a subset of customers geographically distributed. Moreover, each AFS is supposed to have an unlimited number of fueling pumps and then, an AFV never waits for refueling. On the contrary of the G-VRP, the G-VRP with Capacitated AFSs (G-VRP-CAFS) realistically assumes a limited number of fueling pumps at stations and then, that the refueling operations may overlap. We propose a Greedy Randomized Adaptive Search Procedure for efficiently addressing also large-sized instances of the G-VRP-CAFS. Computational results, carried out on both benchmark instances and large-sized instances, show the effectiveness and the efficiency of the proposed method.

4 - A matheuristic for the robust integrated airline scheduling problem
Mohamed Ben Ahmed, Lars Magnus Hvattum, Mohamed Haouari

The airline-scheduling problem aggregates three airline planning processes: fleet assignment, aircraft routing, and crew pairing. Given a daily flight schedule and a set of aircraft fleet, the problem assigns aircraft and groups of crews to each flight contingent on aircraft maintenance restrictions and crew work rules. This problem has been typically disaggregated into several sub-problems, where the fleet assignment problem, which is solved utmost, separates the flight network into subnetworks according to fleet types. A set of periodic aircraft rotations and crew pairing, respectively, are generated afterward for each subnetwork. Admittedly, this divide-and-conquer strategy offers the significant advantage of considerably reducing the computational burden, but at the cost of producing suboptimal, and non-robust solutions into the bargain. Indeed, the produced solutions are by far less flexible and fail to accommodate robustness features which translates into delayed and canceled flights. In this study, we describe a polynomial-size mixed-integer programming model for the robust integrated problem. Robustness is appended in the model by restricting short connections into the schedule and forcing crews to follow aircraft. We propose next a matheuristic solution approach to solve it. The matheuristic hybridizes a decomposition approach and a proximity search algorithm. Computational experiments on realistic data, obtained from a major US airline carrier, are performed.

■ WC-36

Wednesday, 12:30-14:00 - Virtual Room 36

Game Theory, Solutions and Structures V

Stream: Game Theory, Solutions and Structures
Invited session
Chair: *Jacek Mercik*

1 - Cost allocation for collaborative hub networks
Ecem Konak, Gultekin Kuyzu

Collaboration is an effective approach not only in terms of cost savings but also reduction of the carbon emissions. Hub networks take advantage of scale economies through the bundling of flows. Merging hub networks through horizontal collaboration unlocks further economic and environmental advantages. We consider the problem of designing a collaborative hub network as a cooperative game and show by an example that the core of the game doesn't always have to be nonempty. We have used different game theoretical approaches for the allocation of joint costs due to the collaboration. Extensive numerical experiments have been conducted to gain insight into the features of the corresponding cost allocation game and discuss the behaviour of different game theoretical solution concepts. Computational study has been carried out on random instances and the performance of the nucleolus, the Shapley value and the least core methods are evaluated in terms of different fairness notions such as relative savings and stability concepts.

2 - Different views of multiple alternatives and a priori coalitions for power indices
Oscar Oliver, Xavier Molinero

Shapley-Shubik and Banzhaf-Owen power index give a normalized measure of the voting power that a player has in a simple game. Both indices have been extended by Owen (1977) for games in which the players form a priori coalitions. Later, Bolger (1993) extended these indices for games where the players have more than two alternatives. These extended indices are reduced to the original indexes when all a priori coalitions have cardinality 1 and there are two alternatives. Here, we present some alternatives for interpreting a priori or multiple alternatives applied to some real examples. Some cases do not reduce to Shapley-Shubik and Banzhaf-Owen indices when coalitions have just cardinality one with two alternatives, other new cases reduce to originally proposed indices. *This research has been partially supported under grants PID2019-104987GB-I00 (JUVOCO) and MDM-2014-044 (BGSMath).

3 - Implicit power indices for indirect control
Jochen Staudacher, Linus Olsson, Izabella Stach

This presentation deals with measuring indirect control in complex corporate shareholding networks using the concept of power indices from cooperative game theory. We focus on the approaches by Mercik-Lobos and Stach-Mercik which measure the control power of all firms involved in shareholding networks with algorithms based on the raw Johnston index. We point out how these approaches can be generalized replacing the raw Johnston index by various other power indices in a modular fashion. We further extend the algorithmic framework by investigating more than one regression and present requirements for software and modelling. Finally, we test the new framework of generalized implicit power indices for a network with 21 players and discuss how properties of the underlying power index like efficiency or null player removability influence the measurements of indirect control.

4 - Mean Value of Nodes in Communication Structure via Sub-Additive Cooperative Game
Jacek Mercik, Barbara Gladysz

Communication Structure is a multigraph with the parameters of signal transmission through given structure. In game theory-based language (cooperative games), the players are the nodes of the multigraph. The existing connections (graph structure) determine possible coalitions (precoalitions) and define the value of a given coalition as function of possible transfers between players (nodes) in this coalition. The game is called sub-additive iff its characteristic function is sub-additive. The notion of subadditivity has its sense in case of some special coalition games, namely market or communication structure games.The Shapley Value is efficient value of cooperative games.There are many different Shapely value modifications related to the modification of these axioms. For issues related to cooperative games on graphs, the basic set of axioms is the set introduced by Myerson: monotonicity (strong and independence axioms. In classical cooperative game we expect the so-called Individual rationality: No player receives less than what he could get on his own. In the proposed estimation of the value of the node of the communication multigraph (Mean Value of Nodes), we depart from this assumption, which means that the characteristic function of such a game may be a sub-additive function. It can be assumed that in some cases a given player is ready to "pay extra" just to become a member of a given coalition.

■ WC-37

Wednesday, 12:30-14:00 - Virtual Room 37

EJOR: policy, facts and highlights

Stream: OR Journals
Invited session
Chair: *Roman Slowinski*

1 - A new hybrid classification algorithm for customer churn prediction based on logistic regression and decision trees" (EJOR 2018): A review and update
Koen W. De Bock, Arno De Caigny, Kristof Coussement

The logit leaf model (LLM) is a hybrid algorithm for binary classification that combines decision trees and logistic regression and was designed to join their forces and overcome their respective weaknesses. An LLM model compiles an initial segmentation of the data at hand through a decision tree, followed by a logistic regression estimated for every leaf node. The LLM has gained a lot of traction in several research communities since its introduction in EJOR at the beginning of 2018. We believe this attention can be partially explained by its simplicity since the LLM combines two easily understood, well-known, and broadly available constituent classifiers in an intuitive manner. Moreover, the LLM was demonstrated to exhibit two desirable classifier characteristics in the context of customer churn prediction, which are both pursued in other domains as well: competitive predictive accuracy as well as deep model insights. This presentation revisits our EJOR publication featuring the LLM's application to customer churn prediction and identifies key ingredients that we believe contributed to its acceptance and dissemination. It also provides an overview of recent applications and adaptations in other domains and sets an agenda for future research.

2 - Solving the flexible job shop scheduling problem with sequence-dependent setup times
Liji Shen, Stéphane Dauzere-Peres, Janis Sebastian Neufeld

In our study, we address the flexible job shop problem with sequence-dependent setup times to minimize makespan. As an extension to the classic job shop scheduling problem, an operation can now be performed on a set of eligible machines in our setting. This, in turn, increases flexibility, practicality, as well as reliability of manufacturing systems.

A mathematical model is first presented to formulate the scheduling problem under study. Our focus afterwards is placed on deriving structural properties based on disjunctive graphs. We are particularly interested in theorems on feasibility and quality assessment of solutions. This theoretical analysis, in fact, effectively guides our algorithm development. We next propose a tabu search algorithm where feasibility check and lower bound determination become integral. As a result, the search process is quickly driven to promising solution space by discarding infeasible as well as inferior solution candidates.

To evaluate the performance of our tabu search, we have conducted extensive experiments. Benchmark instance sets for flexible job shops are first tested. Our tabu search is able to outperform several existing metaheuristics. Similar results are observed after including sequence-dependent setup times in the benchmark problem instances. The improvement also grows with instance flexibility and problem size. In addition, the results confirm the efficiency of our propositions. The talk will conclude with a discussion on our on-going work.

3 - Policy and facts about the European Journal of Operational Research (EJOR)
Roman Slowinski, Emanuele Borgonovo, José Fernando Oliveira, Steffen Rebennack, Ruud Teunter, Mike Yearworth

The session starts with two presentations done by authors of representative and highly cited papers published recently in EJOR. They represent two categories: Innovative Application of OR, and Theory & Methodology. Some further research developments and practical implications that followed these publications will be given by their authors. Then, the editors of EJOR will explain their editorial policy and will give some current characteristics of the journal. They will also describe their approach to evaluation and selection of articles and will point out topics of OR that recently raised the highest interest. In the last part of the session, the editors will answer some general questions from the audience.

■ WC-38

Wednesday, 12:30-14:00 - Virtual Room 38

Coordination and Competition in Humanitarian Supply Chains

Stream: Humanitarian Operations
Invited session
Chair: *Anna Nagurney*

1 - **Coordination in Humanitarian Supply Chain Management: A Literature Review**
Deepak Srivastav, Lijo John, Anand Gurumurthy

Coordination in humanitarian operations is one of the major challenges, as the humanitarian environment hosts a large number of organizations such as government, military, local and international aid organizations, local population, and private companies among others. All the entities may have different objectives and expertise varying at multiple levels. No one organization can respond effectively in limited time and resources to a major disaster the need for coordination is highlighted in several recent literature reviews as well as other practitioner reports on the humanitarian supply chain (HSC). While coordination in HSC has received a great deal of attention from researchers in the recent past, there are no reviews focusing on coordination in HSC. We have performed systematic and bibliometric review of 114 research papers from the Scopus database. We have summarized the literature by different categories and methodologies used over the period of time. Further co-occurrence analysis is performed using author keywords which are summarized in 5 distinct clusters. Which are (Information Sharing and Humanitarian Operations, Preparedness phase and horizontal coordination, Post-disaster coordination between aid agencies, Barriers in coordination and CSR). Thematic analysis is provided to understand the degree of maturity in each cluster. The study highlights the lack of empirical studies and last-mile delivery issues in coordination in HSC.

2 - **A Multicountry, Multicommodity Stochastic Game Theory Network Model of Competition for Medical Supplies Inspired by the Covid-19 Pandemic**
Anna Nagurney, Mojtaba Salarpour

We construct the first stochastic Generalized Nash Equilibrium model for the study of competition among countries for limited supplies of medical items (PPEs, ventilators, etc.) in the disaster preparedness and response phases in the Covid-19 pandemic. The government of each country is faced with a two-stage stochastic optimization problem in which the first stage is prior to the pandemic declaration and the second stage is post the pandemic declaration. We provide the theoretical constructs, a qualitative analysis, and an algorithm, accompanied by convergence results. Both illustrative examples are presented as well as algorithmically solved numerical examples, inspired by the need for N95 masks and ventilators. The results reveal that, in addition to the preparedness of countries before the pandemic declaration, their ability to adapt to the conditions in different scenarios has a significant impact on their overall success in the management of the pandemic crisis. The framework can capture competition for other medical supplies, including Covid-19 vaccines and possible treatments, with modifications to handle perishability.

3 - **Preparedness in Humanitarian Supply Chains - Exploring the Benefits of Investments in Different Operational Settings from Cost, Time, and Social Impact Perspectives**
Tina Wakolbinger, Jonas Stumpf, Maria Besiou

Humanitarian relief operations are highly dynamic and complex endeavors in particular when they are carried out in response to sudden-onset emergencies. To deliver their life-saving assistance under most difficult conditions, humanitarian organizations choose different operational settings ranging from centralized settings with strong capacities at global hubs to decentralized settings with strong presence in the countries. Investing in supply chain preparedness is considered a powerful trigger to improve the operational performance of humanitarian organizations, ultimately enabling them to provide more assistance with fewer resources. However, very little scientific evidence exists on the actual impact of preparedness investments in the humanitarian space. Using system dynamics methodology, we model the humanitarian supply chain to analyze the impact of preparedness investments with respect to cost savings, lead-time reductions and local social impact in different operational settings. To quantify the results, we introduce the return on investment concept into humanitarian operations. We applied the model in five case studies with humanitarian organizations of different sizes and organizational structures. When comparing organizations with centralized, decentralized and hybrid settings in the non-investment scenario, we find that centralized and hybrid settings are more costly and generate less social impact than the decentralized setting.

4 - **Allocation of Nonprofit Funds among Program, Fundraising, and Administration**
Telesilla Kotsi, Arian Aflaki, Goker Aydin, Alfonso Pedraza-Martinez

US nonprofits declare annually three expenses: program spending to meet their beneficiaries' needs; fundraising spending to raise donations; administration spending to build and maintain capacity. Charity watchdogs expect nonprofits to prioritize program over other expenses. We study when such expectations may be counterproductive. The intertemporal tradeoffs among program, fundraising, and administration shape nonprofits' operations but have received scant attention in the literature. We provide insights on how nonprofits can manage these tradeoffs to optimize budget allocation. We characterize the optimal budget allocations to program, fundraising, and administration using a two-period model, which also includes the nonprofit's capacity, return on program (the net value of program to beneficiaries) and uncertain future needs of beneficiaries. The optimal allocation depends on the nonprofit's capacity. At high capacity, the nonprofit should spend on administration just enough to maintain its existing capacity. At moderate capacity, the nonprofit should still just maintain its existing capacity, but also limit its program spending, so that it has money for fundraising to raise a budget that will use up its capacity. At low capacity, the nonprofit should increase administration spending to expand its future capacity. We use public data to compare our model's prescriptions with the actual budget allocations of a leading network of foodbanks.

■ WC-39

Wednesday, 12:30-14:00 - Virtual Room 39

Emerging Research on Education, Competences and Labor Markets 2

Stream: Emerging Research on Education, Competences and Labor Markets
Invited session
Chair: *Marek Goliński*
Chair: *Małgorzata Spychała*

1 - **The measurement and decomposition of productivity change with environmental variables: A conditional nonparametric frontier analysis approach**
Jose Manuel Cordero, Juan Aparicio, Cristina Polo

Contextual variables usually play a main role in explaining relative efficiency differences in many empirical applications. Nevertheless, most studies focused on analyzing productivity changes do not account for the influence of these variables, especially those adopting a nonparametric approach. Johnson and Ruggiero (2014) represent one of the few exceptions. These authors propose a decomposition of the traditional Malmquist productivity index by including an additional component (environmental harshness) for which they rely on the traditional one-stage model proposed by Banker and Morey (1986).

In this paper, we propose an alternative method to incorporate information about contextual variables in Malmquist productivity decompositions. Specifically, we propose to use the nonparametric conditional approach developed by Daraio and Simar (2005, 2007), which has several advantages over the traditional one-stage model. Using this innovative approach, we can obtain an additional decomposition of the "efficiency change" term in the Malmquist index that allows us to measure how much of this term is explained by contextual factors (Z). The usefulness of the proposed method is illustrated through simulated and real data.

2 - A Search Algorithm for the Menu Planning Program
Francisco Martos-Barrachina, Laura Delgado Antequera, Monica Hernandez, Rafael Caballero

The menu planning problem has often been regarded as an NP-Complete combinatorial problem. Without eluding complexity, and therefore, regarding it as a complete n-day menu for a person or group of people where recipes are the variables of the problem, semi fixing the rations, so avoiding continuity, it becomes an integer combinatorial problem. In this context, classic linear programming is off the table, and current trends in operational research are dominated by the search and implementation of different heuristic algorithms to find feasible solutions to it. These algorithms include Genetic, Bacterial Foraging, Branch and Bound or Branch and Cut. In this case, operationally, the search for an ample feasible space presents a great challenge. Finding a rich feasible set and thoroughly studying it becomes crucial, in order to being able to find an optimal solution. In our work, we propose a hybrid Greedy Randomized Adaptive Search Procedure (GRASP) algorithm combined with a Variable Neighbourhood Search (VNS) to rapidly generate a vast pool of candidate solutions as a first step before optimizing an objective function. We generate an array of random seeds, and using an extended Tchebycheff objective function where we measure the distance to the feasible region, we push the best seeds towards it. Local searches allows us to find multiple feasible solutions and then we densify the feasible region by combining different candidates.

3 - HR Analytics in Determining Employees for Stress Management Counseling
Biljana Panic, Ivana Kovacevic, Achilleas Anagnostopoulos

Even medium-sized companies use employees' e-databases in order to collect and store valuable data about employees, using different decision support systems for retrieving relevant information in the decision making process. Our database covers a sample of 1527 employees' gathered in the period of the economic crisis in Greece that provokes the need for different strategies for employees to cope with stress brought in an organizational setting. Along with "usual suspects" of workplace stress, there is an additive effect of the financial crisis and situation in the labor market.

Employees are facing the fact that their job brings additional stress and organizations ought to provide strategies for stress relief and employees' health preservation. Meta-analyses of the studies of stress management in work settings corroborate the fact that the effect of the interventions might be reduced due to the non-selective approach to stress management training deliverance. To deliver the optimal decision while targeting and recruiting candidates for stress management counseling, we are offering the decision making model provided by KNIME Analytics Platform. The employees' data are collected by using WERS 2011 Questionnaire. To provide a decision making model we extracted factors covering demographics, job characteristics, workplace features, attitudes toward work, the possibility to participate in decision making, and income.

■ WC-40

Wednesday, 12:30-14:00 - Virtual Room 40

Governance Analytics

Stream: Governance Analytics
Invited session
Chair: *Cathal MacSwiney Brugha*

1 - Introduction to Autonomous Weapon Systems - An Ethical Point of View
Marcus Frølich, Mo Mansouri

Autonomous Weapon Systems (AWS) represent both the present and future of modern warfare. With them comes both desirable advantages and a wide range of new challenges, especially concerning the ethics of war. We seek to highlight some of the most relevant advantages and challenges with AWS in order to get a more well-informed discussion. The paper comprises a wide range of contexts for the systems. By creating a causal loop diagram, the dynamics of what influences the use of AWS in warfighting and acceptance by the general public is modeled. Key leverage points and suggestions for dampening factors to some of the challenges are highlighted.

2 - Refugee Allocation Mechanisms: Theory and Applications for the European Union
Petros Xepapadeas, Yiannis Mourtos

We study a relocation problem which consists of allocating a given number of refugees – who are heterogeneous with respect to country of origin and characteristics such as gender, age or educational level – from Greece to other European Union countries which have pledged to accept a certain number of refugees. To study this problem, we developed a conceptual framework consisting of three allocation methods: sequential multi-agent resource allocation, simultaneous allocation, and two-stage allocation. In these methods we incorporate preferences by assuming that the destination countries have their own preferences regarding refugee characteristics, but that they also try to consider the refugees' preferences for the destination countries. While these methods vary in design and execution, all three aim to create a more equitable allocation methodology for both the refugees and the destination countries. These methods could also be applied to other similar types of allocation problems.

3 - Sectorization problems - ongoing research
José Soeiro Ferreira, Ana Maria Rodrigues

Sectorization refers to dividing a whole into smaller parts, the sectors, achieving some goals, or facilitating an activity. Generally, several criteria are involved, which makes the optimisation problems more complex. Typical applications occur in several contexts, such as political, health and school districting, social networks and sales territory or airspace assignment.

The presentation will introduce Sectorization, current and new criteria, and focus on the current research project's ideas. We will refer to novel solution methods based on Genetic Algorithms, Integer Programming, and Non-dominated Sorting Genetic Algorithm-II and III. Moreover, we will outline a new Web-based Decision Support System for Sectorization. A mention of concrete implementations involved in the project concludes the presentation.

■ WC-41

Wednesday, 12:30-14:00 - Virtual Room 41

OR Meets Computation 1

Stream: OR Meets Computation
Invited session
Chair: *Burcu Gürbüz*
Chair: *Aydin Teymourifar*

1 - New Models for Solving Resectorization Problems
Aydin Teymourifar, Ana Maria Rodrigues, José Soeiro Ferreira

In sectorization problems (SPs), a large territory is divided into smaller sectors according to some criteria like equilibrium and compactness. SPs have many applications in different areas such as transportation, healthcare management, energy and irrigation. In the resectorization problems (ReSPs), there is an obtained solution for the previous moment and it is aimed to acquire a new solution according to some changing conditions. We propose new models to solve ReSPs, which cover basic sectorization problems as well as the models with service centres. It is assumed that between moments some changes occur in the coordinates, demands of some points. Also, some points are added into or removed from the problem. The basic idea of the models is that the difference between the two solutions for two different moments should be minimized or limited to an upper limit. The first case is defined as an objective function, while the second one is managed with a constraint. We also generate new benchmarks, for which a new solution method is developed.

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2 - Linear Optimization for Electron Tomography Reconstructions
Juan Manuel Muñoz-Ocaña, Jose J. Calvino, Elena Fernandez, Miguel López-Haro, Antonio Manuel Rodriguez-Chia

Electron tomography is a technique for imaging three-dimensional structures of materials at nanometer scale. This technique consists on reconstructing nano-objects thanks to projections provided by a microscope from different tilt angles. These projections are a group of parallel electron beams which go through the particle to modify their intensities. These intensities, which are called sinograms, are the inputs of our reconstruction models.

The idea behind this reconstruction model is to solve an optimization model that minimizes the norm of the difference between the sinogram and the theoretical projection. Among them, nowadays, most popular reconstruction models are based on total variation minimization considering the sum of the l2-norm of the image gradient as well as the deviation of the reconstructed sinogram with respect to the original data, measured with the l2-norm. We consider an l1-norm total variation model which provides good quality reconstructions. The model we propose removes a high level of noise from the reconstruction recovered. Furthermore, some linear programming techniques are used to provide one efficient way of solving the resulting complex model for real situations.

■ WC-42

Wednesday, 12:30-14:00 - Virtual Room 42

Banking risk management I

Stream: Enterprise risk management
Invited session
Chair: *Ioannis Thanos*

1 - M&A in Greek banking and their impact on the financial system
Ioannis Thanos, Ioannis Katsampoxakis, Apostolos Christopoulos

This paper examines the impact that some possible mergers between the four largest Greek banks may have on the stability and competition of the Greek banking sector. In order to be able to draw conclusions about the impact that an increase in the concentration of the banking sector will have on its competitiveness and stability, we consider the relationships concentration - competition and concentration - competition - stability for the period 2008-2018. For the purpose of measuring competition, we used as a proxy the Lerner index and for the concentration and stability, the Herfindahl-Hirschman and Bank Z score indicators respectively. The results in the model that studied the first relationship show no significance between the two which favors the theory of Effective Structure. In the model that studies the other relationships we found that the competition has a positive and linear relationship with stability while for the concentration we found again not a significant relationship with stability. Our deduction from these results is that an increase in concentration due to mergers or acquisitions has no effect on the market power of the banks or their stability and if banks focus more on being more effective in their results than being bigger to increase their market power, this may have a positive effect on stability.

2 - What "fair interest" should mean for the retail loan market?
Darie Moldovan

In this work we build and compare two application scorecards based on data gathered from two different financial institutions from Romania: a retail bank and a non-banking financial institution (NBFI). While both provide loans for individuals, there is a wide spread between interests charged, presumably based on the default risk. Traditionally, the NBFIs are charging high interests to their clients, who usually don't qualify for a loan with a bank, but is this practice entirely justified by the high risk of default? Our approach tries to quantify the fair interest spread between the two types of loans for the Romanian market and to evaluate the current status of this market.

3 - PreBit: an NLP enhanced prediction model for Bitcoin price using Twitter
Yanzhao Zou, Dorien Herremans

Bitcoin, with its ever-growing popularity, has also demonstrated unparalleled price volatility since its origin. This volatility, together with its decentralised nature, make Bitcoin highly subjective to speculative trading as compared to more traditional assets. We are interested in studying whether social media discussions from the general public on Bitcoin have predictive power for extreme future price movements. To obtain such discussion contents, a dataset of 5,000 daily Tweets (or the maximum number available that day) were collected from 2015 to 2019 containing the keyword "bitcoin". Previous studies have used the Bag of Words (BoW) approach with logistic regression to show that a link exists between Twitter sentiment and daily price on a short time frame of twenty-one days (Colliani, 2015). In our study, sentence-level BERT embeddings pre-trained on financial lexicons were utilised in an attempt to capture not only the sentiment but also the contents of the tweets. By combining these embeddings with a Convolutional Neural Network, we closely examine the link between the public tweet contents and significant market movement over a much longer period of time. We also propose an ensemble of our NLP model and a baseline price model to explore how we can augment the performance of traditional price models with NLP based on Tweets for extreme price movement prediction.

4 - Why do not firms shift risk near distress? A theoretical explanation
Katarzyna Romaniuk

It is generally accepted that theoretically, firms near distress should shift risk. However, it seems that the opposite behavior occurs in practice: firms rather decrease risk-taking. The main argument put forward by the literature to explain this behavior is that the risk-shifting incentive is being opposed by the risk-management incentive. We propose a novel argument based on the interplay of Ross's (2004) effects of convexity, translation and magnification, applied in a continuous-time portfolio setting a la Merton (1971).

■ WC-43

Wednesday, 12:30-14:00 - Virtual Room 43

Sports analytics

Stream: OR in Sports
Invited session
Chair: *Dimitris Karlis*

1 - Make it to the podium - predicting biathlon pursuit outcomes based on sprint race performance
Christoph Herrmann, Thomas Kirschstein

Biathlon is one of the most popular winter sports in Europe. This is justified on the combination of two disciplines (rifle shooting and cross-country skiing) on the one hand and the unpredictability of race results on the other hand. But Pursuit competitions may be an exception, since they are based on the standings of the corresponding Sprint race. For this reason, it is interesting to investigate if it is possible to predict the Pursuit podium with respect to the winner of the Sprint race in biathlon. The paper addresses this question and uses 76 Pursuit races from Women's Pursuit and Sprint races between the seasons 2008/2009 and 2017/2018. Additionally, 5 machine learning algorithms are compared with respect to different goodness-of-fit metrics. Because of the particular data structure, the algorithms are performed on non-standardized and block-standardized features. The analysis identifies that the neural networks can handle a wide range of features and they achieve the highest Cohen's kappa for the original data. The handicaps of rank four and five and the average missed shots ratio are the most important variables. Furthermore, a deeper analysis shows that generalized linear models and naïve Bayes classifiers achieve good results, too. But they need a more advanced preparation and feature selection. Moreover, the paper examines that the complex structure of the data is easier to pick up for the original data especially in the neural networks.

2 - On estimating changes in cricket run-scoring through multiple testing
Moinak Bhaduri

Despite the availability of educated guesses, the run-scoring process in a game of cricket remains challenging to model. Changes in run-gathering may be triggered by factors both blatant (the dismissal of a batsman, the introduction of a good bowler, etc.) and subtle (the stage of the innings, the state of the tournament, etc.). Through this work, I will demonstrate the applicability of a novel statistic, constructed through time-reversal, to unearth such structural breaks. An innings will be modelled by a self-exciting point process, and an algorithm will be proposed to estimate changes in both the immigrant and offspring intensities. I will elaborate on how the proximity of such identified change points (through metrics such as the Hausdorff) may be exploited to pin-point "turning points" in a match, or to cluster similar games in a tournament, or examine whether a tournament is gaining or losing popularity with the passage of time. Extensions to other contexts will be offered.

3 - Modelling a football match as a Markov process: Estimating the effect of offensive and defensive strengths on winning probability
Nobuyoshi Hirotsu, Keita Inoue, Kenji Yamamoto

In this paper, we use a Markov process model of a football match in order to estimate the effect of teams' offensive and defensive strengths on winning probability. In the model, we divide the pitch into nine areas, and defined the states of the model according to the ball location area, the team possessing the ball, and the state of goal scoring. Using data on transitions between states, we construct log-linear models that express the numbers of transitions between states using factors consisting of the offensive and defensive strengths. We estimate these strengths as fixed effects and random effects, and obtain suitable fixed effects models and mixed models that minimize Akaike's information criterion and Bayesian information criterion, respectively. We also estimate the effect of a change of these strengths related to possession on probability of winning a match, and provide a numerical example of the estimation using annual data from J League Division 1 in the 2015 season.

4 - Using player tracking data in football analysis
Dimitris Karlis, Marius Ötting

Modern analysis in football makes use of tracking data, i.e. we know exactly the position of the players and the ball with a high frequency. Such data can help coaches and scouts in several aspects, including game strategy and tactics, player evaluation, goal analysis, judging referee decision, and talent identification, to name but a few. Here, we consider a unique tracking data set which covers information on a single match that has taken place in one of Europe's top five leagues. In our analysis, we focus on a metric that measures the position of the team on the field aiming at examining several tactical aspects. Our metric is the convex hull created by the players of a team excluding the goalkeeper. It is also referred to as Effective Playing Space (EPS), calculated as the surface area (in square meters) of the convex hull of all players (excluding goalkeepers) as a measure of the playing area used by the players. For our analysis, we consider a novel hidden Markov model (HMMs) for modelling the EPS time series data jointly for the two teams, as they naturally accommodate the idea of a match progressing through different phases, with potentially changing tactics. The unobserved states in our HMM serve for the underlying tactics of a team (e.g. defensive vs. offensive style of play). The model enables to deepen the insights into the tactics of the teams, as interactions between them can be modelled additionally.

■ WC-44

Wednesday, 12:30-14:00 - Virtual Room 44

Technique tasters

Stream: Practice of OR (Making an Impact)
Invited session
Chair: *Sharon Feely*

1 - Problem Structuring: Soft Systems Methodology
Giles Hindle, Ruth Kaufman

There are multiple methodologies and techniques available to the OR practitioner which can result in less understanding of those which may have the most impact. We tend to use that which is most familiar to us when problem solving, but the danger is that other methods may be more relevant and more effective to use in a particular situation. This session will provide an overview of three techniques which are less common in practice in order to give a taste of how they could be used and deployed to enhance your OR toolbox. Each of our expert speakers will help you understand whether this might be useful for you, and if so, where to find out more.

Soft systems methodology (SSM) is an approach to organizational process modelling and it can be used both for general problem solving and in the management of change.

Dr. Giles Hindle is a senior lecturer at Hull University Business School and an associate fellow at Warwick Business School.

2 - System Responses: Discrete Event Simulation
Naoum Tsioptsias

Discrete-event simulation (DES) models the operation of a system as a (discrete) sequence of events in time. Naoum Tsioptsias is a Simulation Consultant with Simul8 Corporation.

3 - Decision Making: Decision Analysis
Gilberto Montibeller

Decision analysis is a systematic, quantitative, and visual approach to making strategic business decisions.

Dr. Gilberto Montibeller is a Professor of Management Science and the Director of Executive Education in the School of Business and Economics at Loughborough University (UK) and a Senior Research Fellow at the University of Southern California (USA).

■ WC-45

Wednesday, 12:30-14:00 - Virtual Room 45

Forecasting and Pricing in Retail

Stream: Demand and Supply in Consumer Goods and Retail
Invited session
Chair: *Winfried Steiner*

1 - Dynamic pricing for the operations of an e-grocer
Martin Waitz, Andreas Mild, Gerald Reiner, Christian Fikar

When improving the operations performance of a grocer in an omni-channel environment, multiple different aspects have to be considered simultaneously. Online customers ask for fast, flexible and reliable deliveries within short-time windows, a high availability and quality of products and a low price - challenging the operations of a grocer. In addition, the grocer has to be quite responsive to handle situations such as low inventories, shifts in demand or aging stocks. One possible way to cope with those challenges is dynamic pricing, especially applicable in an online channel setting. In this work, the potential of dynamic pricing for the operations performance of an e-grocer is investigated. Therefore, a study for consumers has been conducted, focusing on general (online) shopping behaviour and a conjoint analysis. This analysis reveals individual preferences for the online purchase and reception of fresh milk as part of a typical shopping basket, including the willingness-to-pay. Results from this study are used to parametrize a simulation and optimization-based decision support system, investigating operations of an e-grocer. The focus lies on inventory policies and the potential of dynamic pricing to influence the demand. Besides inventory levels, the remaining shelf-life of the product will be considered.

2 - The use of price-only conjoint studies for consumer goods and retail decisions
Friederike Paetz, Winfried Steiner, Peter Kurz

The development of consumer goods by manufacturers as well as related assortment decisions of retailers should involve the analysis of consumer preferences in the run-up. In practice, these are often determined by so-called "price-only" conjoint analyses, which consider the brand and the price attributes only. Estimated preferences in turn enter simulation tools, in which shares for products are simulated within a competitive market scenario. Based on the results, final decisions in favour of or against a product can be derived.

So far, less is known about the most appropriate parameterization of the price attribute in such price-only conjoint studies. We compared the results from four different parameterizations for the price attribute: a global price parameter across brands, brand-specific linear price parameters, a global part-worth utility vector across brands, brand-specific part-worth utility vectors. Using four empirical conjoint data sets, we found the alternative-specific part-worth utility parametrization to outperform all other approaches both in model fit, predictive validity and recovery of real market situations. We therefore strongly recommend the application of this price specification for new consumer goods or retail decisions. Interestingly, this finding coincides with common practice in practical studies, but is opposite to common applications in academic research, the latter which mostly rely on a linear or global price specification.

3 - Evaluating Human Behaviour in Response to AI Recommendations for Judgemental Forecasting
Naghmeh Khosrowabadi, Kai Hoberg, Christina Imdahl

Various advanced systems deploy artificial intelligence (AI) and machine learning (ML) to improve supply chain forecasting. However, planners need to become familiar with these systems and trust them, considering real-world complexities and challenges the systems must adapt to. Planners tend to intervene based on their experience or information, which the systems may not capture. In this context, we study planners' adjustments to AI-generated demand forecasts. We collect a large amount of data from a leading AI provider and a large European retailer. Our dataset contains 30 million forecasts at the SKU-store-day level for 2019, plus variables related to products, weather, and holidays. Our two-phases analysis aims to first identify drivers of adjustments using random forest, a well-known ML algorithm. Second, we investigate when adjustments occur and whether they enhance the accuracy. We illustrate the relations between variables using decision trees. We find an important role for price, freshness, and discounts in making adjustments. We show that most large positive adjustments are more frequent but inaccurate, while most large negative adjustments are accurate but fewer in number. Thus, the planners do not substantially contribute to accuracy. Our findings provide insights for the better use of human knowledge in judgemental forecasting.

4 - Flexible dynamic sales response models to improve retail sales forecasts
Winfried Steiner, Philipp Aschersleben

It is well known that store-level brand sales may not only depend on contemporaneous influencing factors like current own and competitive prices or other marketing activities, but also on past prices representing customer response to price dynamics. On the other hand, non- or semiparametric regression models have been proposed in order to accommodate potential nonlinearities in price response.

In this contribution, we combine nonparametric price response modeling and behavioral pricing theory. In particular, we propose a flexible approach to estimate price-change effects based on retail sales data. We follow adaptation-level and prospect theory for modeling price-change effects and compare our flexible model specifications in an empirical study to benchmark models that either ignore price dynamics or just include them in a parametric way. Functional flexibility is accommodated via P-Splines, and all models are estimated in a fully Bayesian framework.

■ WC-46

Wednesday, 12:30-14:00 - Virtual Room 46

Pricing and Competition

Stream: Revenue Management and Pricing
Invited session
Chair: *Arnoud den Boer*
Chair: *Z. Eddie Ning*

1 - Satisficing Search and Algorithmic Price Competition
Chamsi Hssaine, Vijay Kamble, Siddhartha Banerjee

We study algorithmic price competition in a duopoly under a model of "satisficing" customer behavior. In this model, customers consider the firms in some exogenously determined order of preference until they find a price that satisfices an ideal surplus target, choosing the lowest price they can afford if every firm fails to satisfice. On the one hand, we show that these games have an attractive property: if a pure-strategy Nash equilibrium exists, it corresponds to a set of prices generated by the firms sequentially setting best-response prices in a fixed order. In other words, despite being simultaneous-move games, they have a sequential-move equilibrium structure. Moreover, despite the fact that these games are non-convex, we show that a pure-strategy equilibrium exists and is unique in a wide range of settings. On the other hand, we find that these games are frequently plagued by strictly-local Nash equilibria, in which the price of a firm is only a local best-response to the competitor's price, when a globally optimal response with a potentially unboundedly higher payoff is available. We numerically find that price dynamics resulting from the firms utilizing gradient-based algorithms often converge to this undesirable outcome. We finally discuss extensions of our insights to a general model of "pseudo-competitive" pricing games with multiple firms, allowing for a mixture of loyal, satisficing, and opportunistic customers.

2 - Learning to collude in a pricing duopoly
Janusz Meylahn, Arnoud den Boer

We construct a price algorithm based on simultaneous-perturbation stochastic-approximation (SPSA) and show that, if implemented collaboratively by two price-setting firms in a duopoly, they will learn to form a cartel: their prices will converge to those that maximize the firms' joint profit in case this is profitable for both firms, and to a Nash equilibrium otherwise. In addition, if the competitor is not willing to collaborate but behaves according to a reaction function, we show that the prices generated by our algorithm converge to a best-response to the competitor's price. This is done without communication or explicit signaling, so that implementation of the algorithm would be legal under current competition law. Our analysis shows that collusion by self-learning price algorithms is in theory possible.

3 - Tacit collusion by price algorithms under a multinomial logit model with demand learning
Thomas Loots, Arnoud den Boer

Today, the selling prices of many products and services are determined by algorithms. There are concerns that algorithms of different firms could learn to collaborate instead of compete with each other. The goal of this paper is to show that tacit algorithmic collusion is theoretically possible, specifically in the hub-and-spoke scenario, where different firms independently implement the same type of price algorithm.

We consider a duopoly and adopt the widely used multinomial logit framework to model demand, and propose a sustainable form of collusion, called fair Pareto-optimal pricing, that ensures equal relative gains compared to the Nash equilibrium. We show that fair Pareto-optimal pricing is always profitable for both firms but detrimental for consumers.

Next, we propose a price algorithm that learns the fair Pareto-optimal price if deployed by both firms in the duopoly. The algorithm estimates the unknown parameters of the demand model, computes the corresponding estimated fair Pareto-optimal price, and applies an appropriate price perturbation to ensure that prices are sufficiently dispersed to guarantee consistency of the parameter estimates.

Our algorithm can operate in a setting where prices are public but observed demand is private information, by continuously reverse-engineering the most recent demand observation of the competitor from past prices.

4 - How Does Competition Affect Exploration vs. Exploitation? A Tale of Two Recommendation Algorithms
Z. Eddie Ning

Through repeated interactions with users, firms today refine their understanding of individual users' preferences adaptively for personalized targeting and recommendation. In this paper, we use a continuous-time bandit model to analyze firms that supply content to consumers, a representative setting for strategic learning of consumer preferences to maximize lifetime value. We compare a forward-looking recommendation algorithm that balances exploration and exploitation to a myopic algorithm that only maximizes the current quality of the recommendation in both monopoly and duopoly settings. Our analysis shows that competition can discourage learning. In a duopoly where firms compete for consumers' attention, firms focus more on exploitation than exploration in their recommendations than a monopoly would. Competition increases firms' incentives to develop myopic algorithms but decreases their incentives to develop forward-looking algorithms when users are impatient. Development of the optimal forward-looking algorithm may hurt users under monopoly but benefits users under competition. We are among the first to examine and compare the equilibrium of this multi-agent bandit problem under different competitive scenarios, and our results provide implications for firms on the adoption of AI strategy as well as for policy makers on the effect of market power on innovation and consumer welfare.

■ WC-48

Wednesday, 12:30-14:00 - Virtual Room 48

Modelling of Energy Markets (online)

Stream: Emerging technical and financial aspects of energy problems
Invited session
Chair: *Maria Teresa Vespucci*

1 - Agent-based modelling of market competition among flexibility options using machine-learning techniques
Felix Nitsch, Christoph Schimeczek, Valentin Bertsch

Rising shares of renewable energies and increasing electricity demand pose a challenge to existing power systems. Additionally, new flexibility options (e.g. battery storage, vehicle-to-grid or demand response more generally) enter the markets. In order investigate the resulting new price dynamics on energy markets, we apply the agent-based model (ABM) for electricity markets AMIRIS. ABM is ideally suited to assess such effects caused by the behavior and interaction of novel agents. Operators of flexibility options require electricity price forecasts to plan their bidding strategies. In AMIRIS, an agent provides forecasts to flexibility option agents, either with "perfect foresight" or typical forecasting error statistics. However, the forecasts do not include the behavior of flexibility options themselves, thus failing to reflect scenarios with competing flexibility options. Therefore, we strive for a more holistic electricity price forecast that includes also the behavior of competing flexibility option agents. In preliminary works, machine learning, especially feed-forward networks in combination with long-short term memory networks, proved to be a promising tool to address these challenges. We present a model setup for this improved forecasting technique. This includes the generalization of training data and an improved robustness of predictions. Thus, we provide an adaptable solution for researchers to investigate market competition among flexibility options.

2 - Interactions between energy storage and interconnection in imperfectly competitive markets
Andrew Kilmartin, Adriaan Hendrik van der Weijde

Investment in international electricity interconnectors is booming, particularly in Europe where the European Union has set a 15% interconnection target to be achieved by all member states 2030. Interconnection increases the efficiency of the energy system, but these effects are not equally distributed across all interconnected markets, particularly in the presence of market power and energy storage, both of which are present in Europe. In this paper, we investigate the effects of interconnection, storage, and the interactions between them in imperfectly competitive electricity markets, using a Nash-Cournot equilibrium model of the interconnected UK, Norwegian and Dutch electricity markets. By doing so we can model equilibrium prices and generation levels. We first derive a quadratic optimisation problem that yields an equivalent solution to the equilibrium model. By varying the amount of interconnection between the three markets, we can then identify the impact of interconnection and storage on the system. By doing so we were able to investigate how imperfectly competitive markets behave and how market power complicates the analysis and affects energy prices are affected when interconnection and cross border storage are used. More specifically we can then identify the impact of interconnection and storage on prices at different locations, profits of individual firms, consumer surplus, TSO revenues, as well as overall system costs.

3 - Long-run market equilibria in coupled energy sectors
Julia Grübel, Jonas Egerer, Veronika Grimm, Gregor Zöttl

We propose an equilibrium model for coupled markets of multiple energy sectors. The agents in our model are operators of sector-specific production and sector-coupling technologies, as well as price-sensitive consumers with varying demand. We analyze long-run investment in production capacity in each sector and investment in coupling capacity between sectors, as well as production decisions determined at repeated spot markets. We show that in our multi-sector model, multiplicity of equilibria may occur, even if all assumptions hold that would be sufficient for uniqueness in a single-sector model. We then contribute to the literature by deriving sufficient conditions for the uniqueness of short- and long-run market equilibrium in coupled markets of multiple energy sectors. We illustrate via simple examples that these conditions are indeed required to guarantee uniqueness in general. The uniqueness result is an important step to be able to incorporate the proposed market equilibrium problem in more complex computational multilevel equilibrium models, in which uniqueness of lower levels is a prerequisite for obtaining meaningful solutions. Our analysis also paves the way to understand and analyze more complex sector coupling models in the future.

4 - An optimization procedure for distribution management systems in presence of automatic volt-var controllers
Maria Teresa Vespucci, Marco Rossi, Paolo Pisciella, Giacomo Viganò, Diana Moneta

Power systems are facing a significant revolution in terms of energy generation and consumption. In particular, the generation centre of mass is gradually moving from transmission to distribution system, while new load typologies are supplied and demand response is attracting investors. For this reason, the network management/planning is becoming more complex and control strategies based on optimization are adopted also by distribution system operators. Unfortunately, flexible resources (normally owned by third parties) cannot be always monitored and controlled, especially when located in remote and/or low-voltage areas of the distribution system. On these resources, automatic and stand-alone controllers (i.e. volt-var) are often implemented, in order to solve local issues. Of course, their operation has an impact on network power flows and voltages and, if not considered, can significantly interfere with the control actions decided by the distribution management system. We propose an efficient decision support procedure for the centralized control of distribution system resources, that optimizes their activation in order to solve network loading/voltage congestions and reduce losses. Its novelty is represented by the integration of automatic volt-var controllers within the network model, which allows the distribution system operator to take their impact into consideration when planning control actions.

■ WC-49

Wednesday, 12:30-14:00 - Virtual Room 49

Novel approaches for the performance analysis of queueing systems

Stream: Performance Evaluation of Queues
Invited session
Chair: *Stella Kapodistria*

1 - A queue-length approximation for multi-dimensional queueing models
Rik Timmerman, Marko Boon

Multi-dimensional queueing systems are a fundamental building block in the modeling and understanding of a plethora of dynamic processes, with an extremely broad range of applications, yet (exact) results for such models are typically very hard to obtain or are even lacking. Steady-state distributional results are thus not generally available and even (good) approximations tend to be difficult to derive or to compute for higher dimensions. In this presentation, we focus on a novel approximation scheme, ultimately leading to a better understanding of the stochastic systems at hand. We make use of a functional equation for the probability generating function of the joint queue-length distribution. This functional equation contains several unknown functions which are typically hard to find. We approximate these unknown functions with polynomials, allowing us to approximate the unknown functions by considering the roots of a so-called kernel equation, leading to a solvable set of linear equations. We show the merits of our approach by applying our method to several queueing models from the literature, such as k-limited polling models. The most notable advantages of our approximation scheme are (i) it allows for general service times, which typically is not the case for other state-of-the-art approximation schemes, and (ii) it approximates joint queue-length probabilities for multi-dimensional processes.

2 - Product-form queues and the pass-and-swap mechanism
Jan-Pieter Dorsman

Order-independent (OI) queues, introduced by Berezner, Kriel, and Krzesinski in 1995, expanded the family of multi-class queues that are known to have a product-form stationary distribution by allowing for intricate class-dependent service rates. We further broaden this family by introducing pass-and-swap (P&S) queues, an extension of OI queues where, upon a service completion, the customer that completes service is not necessarily the one that leaves the system. More precisely, we supplement the OI queue with an undirected graph on the customer classes, such that there is an edge between two classes if customers of these classes can be swapped with one another. When a customer completes service, it passes over customers in the remainder of the queue until it finds a customer it can swap positions with, that is, a customer whose class is a neighbor in the graph. In its turn, the customer that is ejected from its position takes the position of the next customer it can be swapped with, and so on. This is repeated until a customer can no longer find another customer to be swapped with; this customer is the one that leaves the queue. This intra-queue routing mechanism is called the pass-and-swap mechanism.

In this presentation, we will see that P&S queues have a product-form stationary distribution, enabling further performance evaluation. Time permitting, we will also study networks of P&S queues.

This presentation is based on joint work with Céline Comte.

3 - Workload analysis of a random time-limited Markov modulated polling model
Stella Kapodistria

In this presentation, we analyze a random time-limited Markov modulated polling model.

For the fluid model, we first derive the Laplace-Stieltjes Transform (LST) of the stationary marginal fluid content/workload at each queue. Subsequently, we derive a functional equation for the LST of the two-dimensional workload distribution that leads to a Riemann-Hilbert boundary value problem (BVP). After taking a heavy-traffic limit, the boundary value problem simplifies and can be solved explicitly.

Allowing for more general (Lévy) input processes, we investigate the transient process-limit of the joint workload in heavy traffic. Again solving a BVP, we determine the stationary distribution of the limiting process. We show that, this distribution coincides with our earlier solution of the BVP, implying that in this case the two limits (stationarity and heavy traffic) commute.

This is joint work with M. Saxena, O. J. Boxma and O. Kella

■ WC-50

Wednesday, 12:30-14:00 - Virtual Room 50

Algorithms in Nonlinear Optimization

Stream: Continuous optimization (contributed)
Contributed session
Chair: *Jennifer Erway*
Chair: *Apostolos Chalkis*

1 - On a new shape optimization approach for solving an inverse geometric problem
Azeddine Sadik, Abdesslam Boulkhemair, Abdelkrim Chakib

In this paper we deal with a geometric inverse problem of Bernoulli's type. We start by presenting the existence of the shape derivative of the cost functional on a class of admissible convex domains, and express its shape derivative by defining and using another way of domain variations based on the support functions and the Minkowski sum. Thus, in order to perform a numerical procedure, we reformulate the considered problem as a shape minimization one. After, we present the shape gradient of the cost functional by computing his derivative with respect to the missing shape. Finally, we give numerical illustration results to show the efficiency of the proposed method.

2 - Majorization-Minimization-Based Levenberg–Marquardt Method for Constrained Nonlinear Least Squares
Naoki Marumo, Takayuki Okuno, Akiko Takeda

A new Levenberg–Marquardt (LM) method for solving nonlinear least squares problems with convex constraints is described. Various versions of this method have been proposed, their main differences being in the choice of damping parameter. In this paper, we propose a new rule for updating the damping parameter that is based on the perspective of majorization-minimization method. Our method solves a convex subproblem inexactly in each iteration, and finds an eps-stationary point after computing the Jacobian and projecting a point onto the constraint set O(1/eps2) times. Moreover, for zero-residual problems, our method converges locally quadratically under a local error bound condition. General first-order methods such as projected gradient methods also have the same O(1/eps2) complexity bound as ours, but fail local superlinear convergence. On the other hand, some higher-order methods achieve local superlinear convergence, but they need to compute the Hessian and to solve subproblems which may be NP-hard in the constrained case. Unlike most algorithms so far, our algorithm achieves both the overall computational complexity bound and local quadratic convergence for constrained nonlinear least squares. Numerical results on compressed sensing show that our method converges faster in many cases than those of existing LM methods and the projected gradient method.

3 - A practical randomized method to solve semidefinite programs
Apostolos Chalkis, Vissarion Fisikopoulos

We tackle the problem of efficiently solving semidefinite programs (SDPs). We design a novel practical randomized algorithm to approximate the optimal solution of an SDP. Our algorithm is based on sampling from the feasible set of SDPs, namely spectrahedron, according to a sequence of exponential distributions restricted to the feasible region. We propose an efficient simulated annealing method to compute a short sequence of densities and to obtain fast convergence. To sample from each density we use the exact Hamiltonian Monte Carlo algorithm, which uses reflective quadratic polynomial trajectories in the interior of the spectrahedron. Our open-source C++ implementation scales up to hundreds of dimensions and outperforms standard software (e.g. sdpa package) for dense, randomly generated SDPs.

4 - A new multipoint secant method with a dense initialization
Jennifer Erway, Oleg Burdakov, Mostafa Rezapour

In this talk, we consider the multipoint symmetric secant method with a dense initialization. Multipoint secant methods are a type of quasi-Newton method that seeks to enforce multiple secant conditions. This method uses quasi-Newton matrices to approximate the true Hessian. These approximations can be indefinite, which makes it natural to embed the matrices in a trust-region method. Historically, the multipoint symmetric secant matrices have been initialized using multiples of the identity matrix. In this talk, we use the compact formulation for the multipoint symmetric secant method to write the approximate Hessian in a revealing way that separates the full space into two subspaces, assigning a different parameter to both subspaces. The resulting initial matrix is a dense matrix, but due to the structure of the compact formulation, it does not significantly increase the storage burden. Both theoretical results and numerical results on the CUTEst test set will be presented.

■ WC-55
Wednesday, 12:30-14:00 - Virtual Room 55

Better Decisions with Data I

Stream: EURO Working Group Data Science meets Optimisation
Invited session
Chair: *Yingqian Zhang*

1 - Prescriptive Analytics in Logistics Management
Leif Meier

Significant research and also progress have been done in business administration, computer sciences and related areas to manage information systems and big data sets driven by a simple question: Can we know what will happen before it happens - and set the right actions accordingly?

A case study from automated container terminals is shown. Data quality is a key factor that endangers the competitive situation of a terminal as it often provides a root cause for major operating issues, e.g. crane delay, breakdown times, process interruptions and others:

We make use of prescriptive analytics in port logistics management to improve the data quality of a TOS (terminals operating system) in automated container terminals. Connecting data sets from multiple sources and the use of prescriptive methods allows us to identify TOS data issues and connected planning issues early, so they can be corrected before they cause relevant damages.

In our studies we identified major classes of re-occurring issues that can not only be avoided, but also be explained and improved based on analyzed options. This is leading to significant cost reduction, improving the competitive situation of the container terminal.

2 - Forecasting the all-time demand of spare parts with Bayesian hierarchical diffusion models
Julius Mehringer

Predicting the all-time demand of spare parts for the time period after production ceased is a central issue in supply chain management in order to reduce costs in terms of storage, transportation, disposal, finance and to maintain a desired level of customer satisfaction. The main problem with modeling the future demand after this "End of Production" is that predictions about the whole product life cycle have to be made in the early stages of this life cycle. Thus, only few observations can be used to base the forecast on, which results in volatile and thus unstable predictions for single spare parts. In this paper, we propose a hierarchical Bayesian formulation for diffusion models in order to obtain valid predictions for the spare part demand during the whole life cycle. This model formulation allows us to 1) learn latent reference classes in order to base the forecasts on similar spare part demand patterns from the past; and 2) incorporate the few demand information already available to adequately scale the diffusion model. We validate the feasibility of our approach with simulation-based experiments. Finally, we evaluate our findings on a real world data set consisting of master and consumption data from 1985-2020 stemming from a big manufacturer of household goods and show that it yields significantly better forecasting results than a standard industry baseline model.

3 - Solving the Online Batching Problem using Deep Reinforcement Learning
Yingqian Zhang, Bram Cals, Remco Dijkman, Claudy van Dorst

This work presents a Deep Reinforcement Learning (DRL) approach for deciding how and when arrived orders should be batched and picked in a warehouse to minimize the number of tardy orders. We approach the problem by formulating it as a semi-Markov decision process and developing a vector-based state representation that includes the characteristics of the warehouse system. This allows us to create a deep reinforcement learning solution that learns a strategy by interacting with the environment and solve the problem with a proximal policy optimization algorithm. We evaluate the performance of the proposed DRL approach by comparing it with several batching and sequencing heuristics in different problem settings.

4 - Differentially Private Resource Allocation
Utku Karaca, Ilker Birbil

We consider a resource allocation problem with private and shared capacities that are used by multiple parties. The problem is formulated using the input data of all parties. In this formulation, the main issue for the parties is the privacy of their input data and the optimal solutions containing their individual decisions. To address this concern, using the structure of the problem, we decompose the main problem into subproblems where each subproblem is solved by the related party. In this way, we eliminate almost all the data-sharing requirements of the main model except the linking decision variables defined for the shared resources. To reach the optimal allocation decisions, each party still needs to share its decision variable on the shared resources iteratively. However, this would result in some information leakage regarding their private information and violate the privacy of the parties. To prevent this, we design an epsilon-differentially private algorithm to hold the privacy of the parties. Additionally, we employ a mechanism to guarantee the primal feasibility of the problem. We show that the resulting algorithm is convergent and differentially private. To discuss the trade-off between privacy and optimality, we also give a bound on the expected distance to the optimal solution in terms of number iterations.

■ WC-62

Wednesday, 12:30-14:00 - Virtual Room 62

Ruth Misener

Stream: Keynotes
Keynote session
Chair: *Gabriele Eichfelder*

1 - Computational Mixed-Integer Nonlinear Optimization
Ruth Misener

Effective computational solution strategies for mixed-integer nonlinear optimization problems (MINLP) typically take advantage of special mathematical structure. This presentation discusses some recent advances in exploiting special mathematical structure for solving MINLP. We also discuss solver software for MINLP.

Wednesday, 14:30-16:00

■ WD-01

Wednesday, 14:30-16:00 - Bulding A, Amphitheatre

Georg Pflug

Stream: Keynotes
Keynote session
Chair: *Rita D'Ecclesia*

1 - Financial Optimization: From data to models to solutions
Georg Pflug

Decision making in Quantitative Finance requires to establish a mathematical model for the considered financial processes. Very often, the model class is chosen ad hoc and without reference to the data; only as a second step data are fitted to the chosen model class. To put it differently, the modeler chooses the framework out of his/her imagination and the empirical check comes later. This reminds to the saying: If you have a hammer, everything looks like a nail. In this talk, we take a different viewpoint. On one hand, (1) we introduce parameter free methods of estimation of discrete stochastic processes for financial optimization and on the other hand (2) we discuss the notion of distributionally robust decision making, that is decision making, when there is some uncertainty about the correct model.

The main structure to be investigated is a stochastic tree, i.e. a discrete stochastic process. Such trees can be considered as approximations to real data processes. In topic (1) we show how to minimize the distance between observation data and the model by some learning strategies. In topic (2) we consider a set of several models, which are all compatible with the observed data and choose a decision which is robust w.r.t. model error. In modeling, one typically cannot avoid to make some assumptions. However, we argue that the aim should be to use as much as possible empirical information in order to avoid a modeler bias. Our approaches will be illustrated by concrete examples.

■ WD-02

Wednesday, 14:30-16:00 - Bulding A, Room A5

Methodological developments in PROMETHEE methods

Stream: Multiple Criteria Decision Analysis
Invited session
Chair: *Yves De Smet*

1 - PROMETHEE based multicriteria benchmarking
Jean-Philippe Hubinont, Yves De Smet

Benchmarking is a common tool used by companies or entities in order to compare themselves with others and so, identify best practices for improvement. Since several decades, Data Envelopment Analysis (DEA) has been a reference method to build stepwise benchmarking in the context of multivariate evaluations. Recently, a similar framework has been proposed, in the Multi-Criteria Decision Aid (MCDA) field, in order to generate multiple step scenarios of improvement. It is based on the Electre Modified Level Outranking (EMLO) method. In addition, a methodology denoted by Post Factum Analysis has been proposed in order to evaluate the robustness of conclusions over the rank or class attributed to an action based on a MAVT preference model and on a TOPSIS model. Ultimately, this model can be seen as a bridge between robustness concern and benchmarking as it can be used to generate a single step scenario of improvement. More recently, a new framework for stepwise benchmarking has been developed in order to be adaptable to valued or binary preference models. We propose to investigate how the later framework can be applied to the PROMETHEE methods. An illustrative case-study is proposed.

2 - Characterization of the exploitation of valued pairwise preference relations in the context of Promethee I and Promethee II decision aid methods
Gilles Dejaegere, Mohamed Ayman Boujelben, Yves De Smet

Multicriteria decision aid consists in helping decision makers to compare (rank, choose, sort, etc.) different alternatives which are evaluated on conflicting criteria. In the last decades, numerous decision aid methods have been developed. Among them, one can cite the well-known Promethee methods family. More specifically, Promethee I and II work as follows. Firstly, all alternatives are compared two by two to form a pairwise comparison matrix. This matrix is then exploited by either computing the positive and negative outranking flow scores (Promethee I) or the net flow score (Promethee II). Finally the alternatives are ranked according to these scores.

Despite the wide use of these methods, there lacks theoretical works about the nature of the flow scores. The aim of this work is to provide a characterization of Promethee I and II. Firstly, a set of hypotheses will be presented which lead to characterize the net flow scores. This approach distinguishing itself by presenting the net flow score procedure as a combination of two distinct methods: one based on the direct pairwise comparison of pairs of alternatives and the second based on the comparison of pairs of alternatives with respect to all the other alternatives of the problem. Secondly, it will be shown that by relaxing the set of hypotheses, the positive and negative outranking flow scores as well as their combination can be characterized in the context of Promethee I.

3 - Beyond multicriteria ranking problems: the case of PROMETHEE
Yves De Smet

PROMETHEE is a well-known multicriteria outranking method that has been applied in hundreds of applications. Its success is due to its simplicity and the existence of user friendly software such as Visual PROMETHEE, Smart Picker or D-SIGHT. If it was primarily developed for (complete or partial) ranking purposes, recent extensions have been proposed in sorting and clustering contexts. Among them, the methods called PROMETHEE TRI and PROMETHEE CLUSTER were first presented in 2004. Unfortunately, these approaches suffered from some drawbacks that we highlight in this contribution. To overcome these problems, authors have developed other extensions such as FlowSort, PCLUST, etc. At first, the purpose of this presentation is to provide a summary of these contributions, to highlight their existing links and list several remaining research questions. Then, from a more general perspective, we will show how a ranking method can easily be adapted to be applied in a sorting or in a clustering context. In addition, we will illustrate how sorting methods can be used to compute complete or partial rankings. These concepts will be illustrated in the specific case of PROMETHEE (but are not limited to it). More globally, we will see that the boundaries between the three fundamental problem settings (ranking, choosing and sorting) are blurred. Finally, issues related to rank reversal problems will also be addressed from this new point of view.

■ WD-03

Wednesday, 14:30-16:00 - Bulding A, Room 3A

OR Meets Computation 2

Stream: OR Meets Computation
Invited session
Chair: *Burcu Gürbüz*
Chair: *Arnaud Knippel*

1 - Spectral decomposition for the optimization of electrical transmission network
Arnaud Knippel

The load-flow equations are the main tool to operate and plan electrical networks. For transmission or distribution networks these equations can be simplified into a linear system involving the graph laplacian and the power input vector. Decomposing the power input vector on the basis of the eigenvectors of the graph Laplacian, we solve this singular linear system. This spectral approach gives a new geometric view of the network and power vector. The power in the lines is then given as a sum of terms depending on each eigenvalue and eigenvector. We analyze the effects of these two components and show the important role played by localized eigenvectors. This spectral formulation yields a Parseval-like relation for the L2 norm of the power in the lines. Using this relation as a guide, we proposed [1] to take into account only a part of the eigenvectors to approximate the power in the lines. Based on this approach, we consider a quadratic program to optimize the dimensioning of the generators on an electrical network and study column generation strategies, where the columns correspond to the eigenvectors of the graph laplacian matrix. This way we can find good solutions without having to compute all of the eigenvectors and solve the full quadratic program. Computations are done on IEEE electrical network cases.

[1]Jean-Guy Caputo, Arnaud Knippel and Nicolas Retiere, Spectral analysis of load flow equations for transmission networks. Engineering Research Express, 2019

2 - Polynomial optimization based schemes for solving AC Optimal Power Flow problems
Edgar Fuentes, Bernard Mourrain, Michaël Gabay

Global solution of the AC Optimal Power Flow (ACOPF) problem remains an active research topic. In particular, convex conic relaxations of the ACOPF problem have attracted the attention of the researchers since convexity in mathematical programs often implies that they can be solved efficiently. In this category and considering the ACOPF problem formulated as a polynomial program, Lasserre's hierarchy of moment relaxations theoretically ensures the global solution of the ACOPF problem at some level of the hierarchy. However, the implementation of moment relaxations as semidefinite (SD) programs becomes rapidly intractable even for the first levels of the hierarchy. Seminal works on the application of Laserre's hierarchy to the solution of the ACOPF problem have shown that the sparsity of the network can be exploited in order to globally solve large-scale power systems. However, further reduction of computational cost is yet to be achieved. In this talk, we will present new tractable convex relaxations of the ACOPF problem where we use additional constraints on the original problem and well-known sparsity-exploiting techniques for SD programming in order to circumvent the necessity of large moment matrices as formulated in moment relaxations.

■ WD-04

Wednesday, 14:30-16:00 - Bulding A, Room 3B

Complex routing and location problems I

Stream: Routing, Logistics, Location and Freight Transportation
Invited session
Chair: *Hani Shahmoradi-Moghadam*

1 - A multiperiod location-inventory-routing problem considering mobile recycling units
Eduardo Alberto Alarcon Gerbier

This paper focuses on a dynamic location-inventory-routing problem involving small-scale, mobile, and modular recycling plants. Due to the miniaturization of these production units and their being embedded in standard containers, it is possible to relocate them from site to site at short notice, allowing for a more agile response to spatial and temporal waste generation. We developed a mixed integer program to relocate the mobile recycling units in such a way that the total costs resulting from waste collection and facility relocation are minimized. The difference in the scope of the location and routing decisions is represented by considering decoupled time scales, allowing relocation decisions to be made only in some defined time periods of the planning horizon. Due to the complexity of this integrated problem, and in order to solve for larger instances, we developed a solution approach that forms the basis for a detailed computational study. The economic value of such a mobile recycling network is investigated through a sensitivity analysis, showing the benefit of movable recycling capacities.

2 - Discrete Cooperative Coverage Models with Alternative Facility Types in a Probabilistic Setting: a Computational Study
Ioannis Giannikos, Maria Michopoulou

We consider location models where the objective is to provide coverage to a set of demand points by locating a number of facilities of different types. The coverage provided to each demand point is the result of the cooperation or the interference among facilities. Facilities may be located at a discrete set of pre-determined sites. The different types of facility refer to the coverage radius that each type may provide. We assume that the coverage provided by each facility type operating at each candidate site is modeled by a probability distribution and that the operation of each facility may be correlated to the operation of other facilities, located at different sites. This scenario may describe situations where the facilities' operation may be disrupted by adverse weather conditions, technical malfunctions, or other problems beyond the control of the system planners. We present a non-linear formulation of the problem where the objective is to maximize the number of demand points that are appropriately covered. We then show how the model can be linearized based on a representation of probabilities through a network structure. We then introduce a solution method based on Benders decomposition and experiment with different classes of randomly generated problems. We explore the effect of different parameters on the final solution and determine the elements that influence the computational performance of the solution method and the final system configuration.

3 - An adaptive large neighborhood search heuristic for a waste collection problem with service type option
Sina Glaeser

Household waste collection via a door-to-door pickup system, as used, for example, in Germany, is reaching its limits due to the increasing volume of waste and the lack of space for even more dustbins in densely populated cities. The collection vehicles drive down every street to empty the bins on the curb, which increases traffic congestion and air pollution. An alternative approach to household waste collection does exist: A bring system, where waste is accumulated at central collection sites with a larger capacity. Citizens would travel an additional distance to dispose of their waste at these central collection sites. At the same time, a bring system can reduce the distance to be covered by collection vehicles because it is no longer necessary to drive along every street. Inspired by the last mile parcel delivery, where the aspects of pickup stores and home delivery are combined to face the challenges of growing e-commerce, in this article both systems of waste collection are combined to enable efficient waste collection in times of growing waste generation rates. In this way, the unique structure of the cities can be addressed. If, for example, it is not possible to set up central collection sites for reasons of space, these areas can continue to be served with a pickup system. The corresponding combinatorial problem that arises when switching from a pickup system to a mixed system is modeled and an adaptive large neighborhood search based solution approach is proposed.

4 - An adjustable decentralized robust optimization approach for mobile supply chains with shared factories
Hani Shahmoradi-Moghadam, Jörn Schönberger, Farzad Avishan, Ihsan Yanikoglu

The need for more flexible and adaptable supply chains and the rapid growth of mass customization have promoted the shared and mobile factories idea. The mobile supply chain (MSC) is an emerging paradigm that aims to help companies provide these capabilities. In MSCs, production, distribution, and delivery of a product family are performed by a mobile factory, which can be carried by truck and shared among different customers, a concept which has sprung from the concept of a sharing economy. In this paper, to optimize production scheduling and the mobile factory routing problem under uncertainty, an adjustable decentralized robust optimization approach (ADROA) is proposed. The ADROA is a multilevel hierarchical optimization method which decomposes an all-in-one model into sub-problems using the Analytical Target Cascading (ATC) method. The proposed decentralization approach not only reduces the problem complexity, but also considers information security and agents' autonomy in the supply chain. On the other hand, to manage the problem uncertainty, an adjustable robust optimized approach is utilized. Accordingly, the value of wait-and-see decision variables can be adjusted after some of the uncertain parameters have revealed their values. By way of example, this study investigates the implication of the ADROA to formulate a bi-level mobile factory routing and production scheduling problem while considering the hierarchy and uncertainty which exist in the decision process.

■ WD-05

Wednesday, 14:30-16:00 - Building Δ, Room Δ105

Pricing complex securities

Stream: New challenges for financial modelling
Invited session
Chair: *Rosella Castellano*

1 - Do Gender Issues and Financial Literacy impact on Italian female managers and entrepreneurs?
Rosella Castellano, Jessica Riccioni, Azzurra Rinaldi

Our study aims at exploring the data set collected through questionnaires filled by 457 Italian female mangers and 109 entrepreneurs. The survey is grounded on their job and personal satisfaction, their perception of gender issues and difficulties in accessing to credit market. Cavalluzzo, Cavalluzzo, and Wolken (2002) and Muravyev, Schäfer, and Talavera (2009) find that female-owned firms are less likely to obtain bank credit than male-owned firms. Muravyev, Schäfer, and Talavera (2012) find that female firm-owners are more likely to be denied bank credit and that they usually pay higher rates on bank loans. Using data on Italy, Belluci, Borisov, and Zazzaro (2010) suggest that female firm-owners face tighter credit constraints in dealing with banks, even though they do not pay higher interest rates. This gap is linked to the level of financial literacy of women in general and female owners in particular. At a global level, women show lower financial literacy levels than men (Atkinson and Messy, 2012; Mottola, 2013; Agarwalla et al., 2015). Our study is inserted

2 - A Treatise on Financial Crises Contagion: The Case of African Securities Exchanges
Sèdjro C. Rodrigue Dossou-Cadja

We model the dynamics of African financial markets' behaviour, in the current global context of international financial integration. In a framework of financial idiosyncratic shocks that takes for reference the last 2008 financial global crisis (GFC), the continent's main financial market indices have been linked to those of a representative sample of developed markets. A dynamic panel Probit model then showed, existence of a fundamentals-based contagion, which occurs from developed markets to African markets, mainly through financial and commercial links, foreign exchange markets, and several domestic economic performance variables. A DCC-GARCH and SVAR running, revealed existence of some asymmetric dynamics in the conditional correlations of returns, between developed and African markets, which is hence an evidence of a psychological or pure contagion game. A determined rule setting policy by the monetary and African public authorities, should strengthen resilience of the continent's financial markets to contagion from developed markets disorders.

■ WD-23

Wednesday, 14:30-16:00 - Virtual Room 23

Optimization for Risk-Critical Engineering Applications

Stream: Engineering Optimization
Invited session
Chair: *Calvin Tsay*

1 - Analyzing trained ReLU neural networks with partition-based MILP encodings
Calvin Tsay, Jan Kronqvist, Alexander Thebelt, Ruth Misener

A MILP encoding of a (ReLU-based) neural network enables many properties to be rigorously analyzed, e.g., verifying robustness of an output (often in classification) within a restricted input domain. The big-M formulation is the predominant approach when formulating a neural network as a MILP, but optimizing the resulting MILPs remains challenging for practical instances, even with state- of-the-art software.

In this work, we present a novel class of MILP encodings for ReLU neural networks, based on partitioning inputs into a number of groups and forming the convex hull over the partitions via disjunctive programming. The formulations are hierarchical: at one extreme, one partition per input recovers the convex hull of a node, i.e., the tightest possible formulation for each node. At the other, one partition for all inputs recovers a big-M equivalent formulation. We propose partitioning strategies that enable intermediate formulations to closely approximate the convex hull with many fewer variables/constraints.

The proposed formulations are used to perform three forms of neural-network analyses: optimal adversarial examples, robust verification, and minimally distorted adversaries. Our computational results show that the proposed formulations outperform the standard big-M approach considerable: 25% more problems solved are within a 1h time limit (average 2.2X speedups for solved problems).

2 - A robust approach to warped Gaussian process-constrained optimization
Johannes Wiebe, Ruth Misener

Constraints in which the same uncertain black-box function occurs multiple times evaluated at different domain points are important in applications where, e.g., safety-critical measures are aggregated over multiple time periods. This work models the black-box function by a warped Gaussian process and reformulates these uncertain constraints into deterministic constraints with probabilistic guarantees using robust optimization. We analyze convexity conditions and propose a custom global optimization strategy for non-convex cases. We apply our approach to two case studies including an industrially relevant oil drilling problem for which we develop a custom strategy for globally optimizing integer decisions.

This work considers a new class of uncertain black-box constraints, modeled by warped Gaussian processes, in which the same black-box function occurs multiple times evaluated at different domain points. Such constraints are important in applications where, e.g., safety-critical measures are aggregated over multiple time periods. We use robust optimization to reformulate these uncertain constraints into deterministic constraints with probabilistic guarantees. We analyze convexity conditions and propose a custom global optimization strategy for non-convex cases. We apply our approach to two relevant case studies and develop a custom strategy for globally optimizing integer decisions in one of them.

3 - A bi-level mixed-integer data-driven optimization approach for the integrated planning and scheduling problem under demand uncertainty
Burcu Beykal, Styliani Avraamidou, Efstratios Pistikopoulos

Supply chain management is an essential problem in many chemical industries, yet the optimal coordination among different layers of the supply chain network is a challenging task. The interconnected decision-making nature of these problems requires a holistic approach to ensure feasible realizations of all activities within a supply chain. Bi-level multi-follower programming is well-suited for the task, as scheduling problems (followers) provide constraints for the decision making in the planning problem (leader). However, there are many algorithmic challenges for this class of mathematical programs, especially when integer variables are present at the follower problems. These challenges are amplified in the presence of demand uncertainty, where planning and scheduling decisions will have to account for unknown product demands. In this work, we investigate the modeling and optimization of planning and scheduling problems under demand uncertainty using bi-level mixed-integer multi-follower programming through data-driven optimization. We extend the DOMINO framework, which is developed to address single-follower bi-level optimization problems, to solve multi-follower formulations. We characterize the performance of our approach on a multi-product batch production plant case study. We further analyze the effects of the scheduling level complexity on the solution performance, which spans over several hundred continuous and binary variables, and thousands of constraints.

■ WD-24

Wednesday, 14:30-16:00 - Virtual Room 24

DEA applications to Sustainability and Development

Stream: Data Envelopment Analysis and Performance Measurement
Invited session
Chair: *Konstantinos Soukakos*

1 - Innovation, productive performance and undesirable outputs across European regions: Are there any missing links?
Eirini Stergiou, Kostas Tsekouras, Konstantinos Kounetas

Convergence among European regions has been one of the most significant objectives of EU. This is of high interest after the New Green Deal and the development of common policies to address climate change through innovation, along with the achievement of economic growth and reduction of inequalities. The joint investigation of economic growth and environmental concerns led researchers to develop models that simultaneously estimate innovation and economic performance. An "open" box of production structure is assumed that examines the links between various stages where the outputs of one stage become inputs to another. The consideration of two distinct, the innovation and production, activities allow to assess the internal mechanism of the entire system by further embodying bad outputs exerted on the environment from the production process. The Directional Distance Function method is utilized to estimate the overall process and the internal sub-processes efficiency. We empirically evaluate the performance of European regional economies from 1999-2018 while we investigate if different weights on the sub-processes could influence the efficiency of the entire system. The research was supported by the Hellenic Foundation for Research and Innovation (H.F.R.I.) under the "First Call for H.F.R.I. Research Projects to support Faculty members and Researchers and the procurement of high-cost research equipment grant"(Project Number: HFRI-FM17-0320)

2 - Environmental performance evaluation: A state-level DEA analysis
Estefania Avilés-Sacoto, Sonia Avilés-Sacoto, David Güemes-Castorena, Wade Cook

In recent years the continuous development of the economic activities in every country has generated undesirable impacts on the environment. The common problems are high water and energy consumption rates, jointly with harmful pollution levels. This situation has gained the research community's attention to explore and analyze the extent to which initiatives to reduce such environmental problems have succeeded. Therefore, it is relevant to have measures that encompasses information on the results obtained by such initiatives. By using the data envelopment analysis (DEA) methodology, it is possible to obtain a measure that provides the efficiency of an entity (for example an industry, state or country) under evaluation. DEA also allows one to compare the performance measures of entities operating in similar circumstances, and identify which entities are performing best given the inputs they use and the outputs they produce. This study evaluates different states in Mexico in terms of their environmental performance and provides a perspective on how environmental initiatives can contribute to protecting and preserving the environment. By solving this problem, the best-performers are identified, and valuable insights are gained as to how each state is carrying out such initiatives.

3 - Waste management evaluation accounting for Sustainable Development Goals: A DEA-TOPSIS approach

Laura Carosi, Giovanna D'Inverno, Giulia Romano

In the 2030 United Nation Agenda, solid waste management is directly related to 12 out of 17 Sustainable Development Goals. Looking at the specific targets, municipalities are supposed to reduce their environmental footprint by improving waste management: prevention, reduction and recycling are the priority. The waste management performance evaluation must consider the municipal efforts towards both the service provision and the accomplishment of the sustainable development targets. An innovative efficiency model is proposed by integrating two different tools, a frontier estimation technique and a multicriteria decision making approach. As for the latter, an environmental indicator is constructed by means of the TOPSIS technique, taking into account dimensions strictly linked to the Sustainable Development Goals. As for the former, municipalities' performance is investigated by suggesting a novel Data Envelopment Analysis model where both volume and ratio outputs are considered and weight restrictions are fixed. The presence of weight restrictions emphasizes the extent of the municipality's willingness to accomplish the environmental targets from the input side. A robust conditional analysis is also provided to investigate the influence of contextual variables on the municipal waste management performance while accounting for atypical observations. The empirical use of the proposed model is shown by assessing the waste management performance of 232 Tuscan municipalities.

4 - Evaluation of Wind Parks with Data Envelopment Analysis (DEA)

Konstantinos Soukakos, Konstantinos Kaparis, Andreas Georgiou

The aim of this study is the evaluation of Wind Parks efficiency using Data Envelopment Analysis (DEA). The main objective, is the classification of Wind Parks based on their relative efficiency, using DEA, the evaluation of the "distance" to the efficient frontier for inefficient units and the detection of efficient peers. The approach is implemented in a set of sixteen specific installations in Greece and the data are drawn from 2019. The model applies the VRS model in input or output oriented orientations. In total seven different scenarios were investigated to examine the dataset under different angles, depending on the combinations of inputs and the orientation. The dataset includes inputs such as power generation, losses, self-consumption and wind speed. All scenarios use a single output namely the generation of electrical power. The model's solution is realized in two phases: In the first phase, each Wind Park is classified as weakly efficient or inefficient, compared to its peers. In the second phase, we further investigate the subset of the initially weakly efficient units to determine the set of fully efficient units. The study concludes with suggestions for the inefficient units, and further research ideas either methodologically-wise, e.g. using additive models, or case oriented, e.g. evaluation of offshore Wind Parks that exhibit an increasing interest among investors.

■ WD-25

Wednesday, 14:30-16:00 - Virtual Room 25

Stochastic Programming in Healthcare

Stream: Stochastic and Robust Optimization
Invited session
Chair: *Emilia Grass*

1 - A Stochastic Optimisation Model to Support Cybersecurity within the UK National Health Service

Emilia Grass, Christina Pagel, Sonya Crowe, Saira Ghafur

Over the past decade there has been a surge of new digital technologies being used in healthcare to help improve the delivery and access of care. At the same time the number of cyber-attacks on healthcare has significantly increased, especially during the current COVID-19 pandemic, posing a threat to the functionality of hospitals and the safety of patients. Therefore, it is vital to be as prepared as possible for the ever-evolving cyber threats. The inherent uncertainty makes it very difficult to plan for future cyber incidents. Stochastic programming can efficiently support decision making by taking uncertainties into account. We propose a two-stage stochastic model to improve the cyber resilience of a healthcare provider by selecting a set of efficient countermeasures in preparation for upcoming cyber incidents. To be optimally equipped even for low-probability high-impact attacks we propose a second optimisation model incorporating the risk measure Conditional Value-at-Risk. Numerical tests highlight the importance of both modelling approaches and reveal what types of countermeasures are most important to increase cybersecurity in the healthcare sector.

2 - Stochastic programming for outpatient scheduling with flexible inpatient exam accommodation

Yifei Sun, Vikrant Vaze

This study is concerned with the determination of an optimal appointment schedule in an outpatient-inpatient hospital system where the inpatient exams can be canceled based on certain rules while the outpatient exams cannot be canceled. Stochastic programming models were formulated and solved to tackle the stochasticity in the procedure durations and patient arrival patterns. The first model, a two-stage stochastic programming model, is formulated to optimize the slot size. The second model further optimizes the inpatient block (IPB) placement and slot size simultaneously. A computational method is developed to solve the second optimization problem. A case study is conducted using the data from MRI centers of Lahey Hospital and Medical Center (LHMC). Results indicate that the overall weighted cost can be reduced by 11.6% by optimizing the slot size and can be further reduced by an additional 12.6% by optimizing slot size and IPB placement simultaneously. Three commonly used sequencing rules (IPBEG, OPBEG, and a variant of ALTER rule) were also evaluated. The results showed that when optimization tools are not available, ALTER variant which evenly distributes the IPBs across the day has the best performance. A Pareto frontier was also developed and presented between patient waiting time and machine idle time to enable medical centers with different priorities to obtain solutions that accurately reflect their respective optimal tradeoffs.

3 - Optimization Models for Allocating Scarce Medical Drugs during Pandemics

Bismark Singh, Steffen Rebennack, Lauren Meyers

We provide general mathematical optimization models for allocating scarce drugs spatiotemporally during pandemics. Drugs - such as vaccines, antibiotics, and antivirals - are allocated from a centralized inventory, such as a federal stockpile, to regional authorities for further distribution on a periodic basis. We address the question of whether such stockpiles should be fully released at the outset or gradually distributed throughout the threat. We find that if the drug or vaccine is expected to have equal benefit across all individuals, then an immediate release is optimal. However, if some population groups are expected to benefit more than others preferentially, then sequential releases that conserve drugs and match peak demand are advisable. In contrast to traditional compartmental differential equation-based models, we use a stochastic programming approach that allows to input scenarios generated from epidemiological models. In the early stages of the COVID-19 pandemic, when widespread testing was unavailable, accurate demands for new drugs was unknown. Then, we mathematically prove that the general problem we consider is NP-complete, even for only two scenarios. We further provide a pseudo-polynomial greedy algorithm for its solution. However, when drugs are available only under a medical prescription - and thus demands are known - we prove the greedy solution is optimal.

4 - Mixed 0-1 two-stage optimization: a case study for emergency response after earthquake disasters

Aitziber Unzueta, Isabel Eguia, M. Araceli Garin

Stochastic optimization problems of practical applications lead, in general, to some large scale models. The size of those models is linked to the number of scenarios that defines the scenario tree, which can be so large that decomposition strategies are required for problem solving in reasonable computing time. Methodologies such as Branch-and-Fix Coordination or Lagrangean Relaxation make use of these decomposition approaches, where independent scenario clusters are given. In this work, we present a technique to generate nested cluster submodel structures from the decomposition of a general two-stage stochastic mixed integer optimization model. These scenario cluster submodels can be embedded in different algorithmic schemes in order to make the chosen solution procedure more efficient. We will consider as a case study a two-stage stochastic mixed 0-1 model that aims to make decisions that help to mitigate the complications of earthquake hazards, particularly in the area of Japan. In the first stage, decisions are made regarding the location of facilities as well as their storage capacity. While in the second one, decisions concern the distribution of stored supplies from the facilities to the affected locations. Uncertainty shall be considered to affect parameters such as demand, the prevalence or validity of stored supplies or the conditions of the transmission network. Computational experience supporting the efficiency of the proposed procedure is provided.

■ WD-26

Wednesday, 14:30-16:00 - Virtual Room 26

Fair Machine Learning

Stream: Ethics in Analytics
Invited session
Chair: *Phebe Vayanos*
Chair: *Paula Carroll*

1 - Unbiased Subdata Selection for Fair Classification: A Unified Framework and Scalable Algorithms

Qing Ye, Weijun Xie

Fair classification concerns the issues of unintentional biases against the sensitive features (e.g., gender, race) in the conventional classification approaches. Due to high nonconvexity of fairness measures, existing methods are often unable to model exact fairness, which can cause inferior fair classification outcomes. This paper fills the gap by developing a novel unified framework to jointly optimize accuracy and fairness. The proposed framework is versatile and can incorporate different fairness measures precisely as well as can be applicable to many classifiers including deep classification models. Many classification models within this framework can be recast as mixed-integer convex programs, which can be solved effectively by off-the-shelf solvers when the instance sizes are moderate. We prove that in the proposed framework, when the classification outcomes are known, the resulting problem, termed "unbiased subdata selection," is strongly polynomial-solvable and can be used to enhance the classification fairness by selecting more representative data points. This motivates us to develop an iterative refining strategy (IRS) to solve the large-scale instances, where we improve the classification accuracy and conduct the unbiased subdata selection in an alternating fashion. We numerically demonstrate that the proposed framework can consistently yield better fair classification outcomes than existing methods.

2 - Learning Fair Optimal Classification Trees

Sina Aghaei, Jack Benson, Andres Gomez, Phebe Vayanos

The increased use of machine learning (ML) in high stakes domains has created an urgent need for ML algorithms that are fair and interpretable and that leverage the available data to its full extent to yield the most accurate predictions. In this paper, we propose a versatile framework for learning optimal and fair classification trees based on mixed integer optimization technology. Our framework is flexible to capture arbitrary fairness notions from the literature such as statistical parity, conditional statistical parity, etc. We evaluate our method on numerous datasets from the literature and investigate the trade-off between accuracy and fairness. We provide an R package that is freely distributed for academic and non-profit use.

3 - A statistical test for probabilistic fairness

Bahar Taskesen, Jose Blanchet, Daniel Kuhn, Viet Anh Nguyen

Algorithms are now routinely used to make consequential decisions that affect human lives. Examples include college admissions, medical interventions, or law enforcement. While algorithms empower us to harness all information hidden in vast amounts of data, they may inadvertently amplify existing biases in the available datasets. This concern has sparked increasing interest in fair machine learning, which aims to quantify and mitigate algorithmic discrimination. Indeed, machine learning models should undergo intensive tests to detect algorithmic biases before being deployed at scale. In this paper, we use ideas from the theory of optimal transport to propose a statistical hypothesis test for detecting unfair classifiers. Leveraging the geometry of the feature space, the test statistic quantifies the distance of the empirical distribution supported on the test samples to the manifold of distributions that render a pre-trained classifier fair. We develop a rigorous hypothesis testing mechanism for assessing the probabilistic fairness of any pre-trained logistic classifier, and we show both theoretically as well as empirically that the proposed test is asymptotically correct. In addition, the proposed framework offers interpretability by identifying the most favorable perturbation of the data so that the given classifier becomes fair.

4 - Tackling Gender Bias: Updates from the EURO WISDOM Forum

Paula Carroll, Annunziata Esposito Amideo

Analytics, machine and statistical learning approaches that rely heavily on data to extract insights and support decision making are at risk of entrenching existing societal biases. Scoring systems make critical recommendations about jobs, finance, insurance and health care. Text analytics systems may be hampered by stereotypical representations and linguistic depictions of gender constructs. Facial recognition systems have been shown to work best for white males with poor performance at recognising women of colour. Care needs to be taking in training such systems. There are no objective algorithms or technologies, all reflect the values and perspectives of their creators in some way. It is essential for OR and analytics to avoid perpetuating gender stereotypes and systems that disadvantage women by explicitly addressing gender bias and by integrating gender aware methods in the framing of OR and analytics problems. The EURO WISDOM Forum aims to support, empower, and encourage the participation of all genders in Operational Research and Management Science within EURO. WISDOM aims to promote a conversation around how OR can be utilised to help create a diverse and inclusive future. This work explores steps toward a better articulation of the gender dimension in OR and analytics research and education. We highlight the recommendations in the WISDOM White paper to promoting gender equality and inclusivity in EURO activities, and related research projects.

■ WD-27

Wednesday, 14:30-16:00 - Virtual Room 27

Vehicle routing II

Stream: Combinatorial Optimization
Invited session
Chair: *Mikael Rönnqvist*

1 - Using a heuristic algorithm with a similarity function to re-scheduling in a home care vehicle routing problem
Juan-Carlos Gutierrez-Vanegas

This difficult times has impose a significant changes in all kind of organizations. In particular, most work must be done at home, entails workers need an ergonomic work station in theirs houses. In order to suitably evaluate the physical conditions of each one collaborator in his home, an specialists must be mobilized to there and, for a national wide organization, this implies a huge number of orders of service (OOS) to manage. A similar problem has been reviewed in the literature as Home Health Care Services and mathematically could be modeled as a CVRPTW. However, in this case, a reduce number of human resources, name here as specialists, are available each week to served each OOS, but, because the unplaned meetings of the collaborators, the number of OOS change week to week, and , in many cases, a re-schedule for the same OOS is necessary, this is the main issue to address. Finally, the service time is considerable, morever, includes a post-processing asynchronous that reduce the overall capacity for each specialists. The solution procedure preeente here is split in two phases. First, a traditional CVRPTW is formulated, then, an heuristic algorithm is used to find a very-good, but non necesary optimal, solution. Next, a similarity function is used to find a affine route, if a reschedule is necessary. The results with several real instances are presented and discussed at the end.

2 - Routing of forwarders
Mikael Rönnqvist, Patrik Flisberg, Victoria Forsmark, Linnea Hansson

Routing of forwarders is similar to a Vehicle Routing Problem but with a complicating aspect. A forwarder picks up small piles of logs at harvest areas and in a network constructed by the harvester. These piles are then put in large piles adjacent to forest roads. The complicating part is that each load can consist of multiple assortments (or products) which must be loaded in a defined but not specific order. For example, it may be possible to load four assortments (e.g. A, B, C and D) but then the piles must be picked up such that all are A, then B then C, and then D. It is also possible for all perturbations of A, B, C and D. Moreover, there are different costs in which sequence they are loaded. For example, it is much worse to have small diameter logs on top of large diameter logs as they will mix with each other and increase the sorting at the forest roads. This limits the composition of the route considerably as compared to a free loading. At the same time, this have a huge potential in improvement compared to current practice with manual planning. The potential size is very large. There may be as many as 10-15 assortments in 1000-2000 piles available at a harvest area. We propose a column generation based on a special dynamic programming method to generate the routs / columns into a set covering model. Results from a detailed case study is presented.

3 - Modeling and Solving the Profitable Close-Enough Arc Routing Problem
Miguel Reula Martín, Angel Corberan, Isaac Plana, Jose Maria Sanchis

Recent technological advances allow many logistic problems to be solved more easily and with less cost. In particular, in meter reading problems, the companies can collect remotely the consumption data of their customers due to radio frequency technology (RFID). In some cases, a vehicle with a receiver travels through a neighborhood and, if it gets within a certain distance of a meter, the receiver is able to record the gas, water, or electricity consumption. Therefore, the vehicle does not need to traverse all the streets where there are meters but a subset of them that are close enough to all meters. In this application, the Close-Enough Arc Routing Problem considers that each costumer is not located in a specific arc, but can be served whenever a vehicle traverses any arc of a given subset. We deal with a generalization of this problem, the Profitable Close Enough Arc Routing Problem (PCEARP) in which a profit is associated with each customer and it is collected (only once) when the customer is serviced. The goal is to find a tour maximizing the difference between the total profit collected and the travel distance. A formulation for this new problem and some valid inequalities are presented, and a polyhedral study of its feasible solutions is conducted. We propose a heuristic and a branch-and-cut procedure for solving the PCEARP, and their performance has been tested on several sets of instances with different characteristics.

4 - A kernel search matheuristic to solve several well-known Vehicle Routing Problems
Diana Lucia Huerta Muñoz, Claudia Archetti, Gianfranco Guastaroba, Roger Z. Rios-Mercado, M. Grazia Speranza

The Vehicle Routing Problem (VRP) is a family of problems which calls for the minimization of the total distribution cost satisfying some operational constraints. In this work, we study several well-known variants of VRPs. While the literature usually offers a specific solution method for each specific variant, we design and develop a unified solution framework that is capable of solving several of them. This algorithm is based on a Kernel Search matheuristic, which has shown a great performance in several combinatorial optimization problems. The main idea of this matheuristic is to identify promising subsets of decision variables and iteratively solve a restricted Mixed-Integer Linear Program on those subsets using a general-purpose solver. Computational experiments are carried out on benchmark instances to show the performance of the proposed matheuristic in comparison with state-of-the-art algorithms.

■ WD-28

Wednesday, 14:30-16:00 - Virtual Room 28

The Role of Mathematical Optimization in Data Science II

Stream: Mathematical Optimization and Data Science
Invited session
Chair: *Víctor Blanco*

1 - Fair and Interpretable Decision Rules for Binary Classification
Connor Lawless, Oktay Gunluk

In recent years, machine learning has begun automating decision making in fields as varied as college admissions, credit lending, and criminal sentencing. The socially-sensitive nature of some of these applications together with increasing regulatory constraints has necessitated the need for algorithms that are both fair and interpretable. In this talk we discuss the problem of building Boolean rule sets in disjunctive normal form (DNF), an interpretable model for binary classification, subject to fairness constraints. We formulate the problem as an integer program that maximizes classification accuracy with explicit constraints on different notions of classification parity. A column generation framework, with a novel formulation, is used to efficiently search over exponentially many possible rules, eliminating the need for heuristic rule mining. We benchmark the performance of our algorithm against other state of the art algorithms in fair and interpretable machine learning.

2 - Optimal Decision Trees at the service of Functional Data Analysis
Cristina Molero-Río, Rafael Blanquero, Emilio Carrizosa, Dolores Romero Morales

Continuously monitoring processes over time entails the collection of great amounts of data. Yet, it may happen that simply observing a finite number of time instants or intervals is sufficient to produce an accurate analysis of the whole period, which is in turn more interpretable and saves both monitoring and storage costs. In this talk, we tailor optimal decision trees to dealing with functional data, where a compromise between prediction accuracy and interpretability is sought. At the same time as the tree model fitting, the detection of time instants or intervals that are critical for prediction is performed. This is achieved through the inclusion of LASSO-type regularization terms. The resulting optimization problem can be formulated as a nonlinear continuous model with linear constraints. If desired, high-order information of the functional data provided by their derivatives can be added in a straightforward manner.

3 - A robust SVM-based approach with feature selection and outliers detection for classification problems

Marta Baldomero-Naranjo, Luisa I. Martínez-Merino, Antonio Manuel Rodriguez-Chia

In this talk, a new robust classification model is presented. This model is based on support vector machine (SVM) and deals with outliers detection and feature selection simultaneously. The classifier is built considering the ramp loss margin error and it includes a budget constraint to limit the number of selected features. In this model we use the l1-norm, a norm with the sparse property, particularly suitable for feature selection. The search of this classifier is modeled using a mixed-integer formulation with big M parameters. Two different approaches (exact and heuristic) are proposed to solve the model. The ideas of the exact approach are based on the ones presented in Baldomero-Naranjo M. et al. (2020) while the heuristic approach is based on the Adaptative Kernel Search, see Guastaroba et al. (2017). Finally, the efficiency of the proposed classifier on real-life datasets is shown.

References M. Baldomero-Naranjo, L. I. Martínez-Merino, and A. M. Rodríguez-Chía. Tightening big Ms in Integer Programming Formulations for Support Vector Machines with Ramp Loss. European Journal of Operational Research, 286:84-100, 2020. G. Guastaroba, M. Savelsbergh, and M. Speranza. Adaptive kernel search: A heuristic for solving mixed integer linear programs. European Journal of Operational Research, 263(3):789 - 804, 2017

4 - Mathematical Optimization Models for Classification in Datasets with Noisy Labels

Víctor Blanco, Alberto Japón Sáez, Justo Puerto

We propose novel methodologies to optimally construct Optimization-based classifiers that takes into account that label noises occur in the training sample. Different alternatives are provided based on solving Mixed Integer Linear and Non Linear models by incorporating decisions on relabelling some of the observations in the training dataset with different paradigms. We will show that this methodology is useful when constructing SVM-based classifiers as well as Optimal Classification Trees. Extensive computational experiments are reported based on a battery of standard datasets taken from UCI Machine Learning repository, showing the effectiveness of the proposed approaches.

■ WD-29

Wednesday, 14:30-16:00 - Virtual Room 29

Network design and routing with logistics applications

Stream: Routing, Logistics, Location and Freight Transportation

Invited session

Chair: *Juan G. Villegas*

1 - Fleet Sizing and Service Region Partitioning for Same-Day Delivery Systems

Dipayan Banerjee, Alan Erera, Alejandro Toriello

We study the linked tactical design problems of fleet sizing and partitioning a service region into vehicle routing zones for same-day delivery (SDD) systems. Existing SDD studies focus primarily on operational dispatch problems and do not consider system design questions. Prior work on SDD system design has not considered the fleet sizing decision when a service region may be partitioned into zones dedicated to individual vehicles; such designs have been shown to improve system efficiency in related vehicle routing settings. Using continuous approximations to capture average-case operational behavior, we consider first the problem of independently maximizing the area of a single-vehicle delivery zone. We characterize area-maximizing dispatching policies and leverage these results to develop a procedure for calculating optimal areas as a function of a zone's distance from the depot. We then demonstrate how to derive fleet sizes from optimal area functions and propose an associated Voronoi approach to partition the service region into single-vehicle zones. We test the fleet sizing and partitioning approach in a computational study that considers two different service regions and demonstrate its pragmatism and effectiveness via an operational simulation. Using minimal computation, the approach specifies fleet sizes and builds vehicle delivery zones that meet operational requirements, verified by simulation results.

2 - A mixed integer linear programming model for the two-echelon inventory routing problem with lateral transshipments

Edgar E. Córdoba-Sarmiento, Javier Arias-Osorio, Laura Y. Escobar-Rodríguez

Inventory management and vehicle routing are critical elements in today's supply chains. Optimizing these logistics operations improves chain performance, increasing service levels and minimizing associated costs. In a dynamic environment, a multi-period planning horizon is considered, where the demand in each period is different, resulting in the need to rethink logistical decisions as delivery generation, units to deliver, customers to serve, sequence of service, delivery scheduling, inventory policy. In this work, we developed a mixed integer linear programming model for the two-echelon inventory routing problem with lateral transshipments (2EIRPT) in which vehicle and storage capacity are considered. The demand of the chain's customers is deterministic for each period and can be higher than the fleet's capacity. Customers are served from distributors, where partial deliveries are allowed. Lateral transshipments are only executed between distributors and are carried out with the second echelon's fleet. The objective function seeks to minimize the total logistics costs: Transportation and inventory. Finally, the proposed model is validated with some numerical examples using computing software GAMS 3.1.1.

3 - Time-transformational Graph Representation of Routing Problems under Disruption

Lanqing Du, Jinwook Lee

As the extended pandemic periods tend to interfere with the supply-chain environment, COVID-19 has posted a profound influence in addressing the flexibility and resilience in supply chain management. Those factors will urge logistics industries to seek flexible routing strategies to build resilience and mitigate disruptions. Third-party logistics service is widely used within the logistics industry even before the COVID-19, and it would be addressed as one of many essential alternatives in logistics fulfillment when facing the rising demand, disruption uncertainty and its ripple effect. This study proposed a time-transformational graph representation framework to find alternative routing solutions when imposing random disruptions that inherently follow a Markov Chain process on the graph nodes. Two sets of dummy nodes are introduced to transform a geographical network representation into a time-distance network representation to create a message-passing network over time. In the message-passing network, node features and edge features are updated periodically, following a set of rules to regulate the logistic network realistically. This study tried to evaluate the ripple effect on a more specific area of the logistics industry. Sensitivity analysis will help the industry decision-maker to diagnose the weak nodes and links within the network and provide timely reactions on using third-party logistics services to build flexibility and resilience under disruption.

4 - Competitive Location Routing Problem: a maximal covering approach
Juan G. Villegas, Juan Pablo Fernández-Gutiérrez

We propose a discrete facility location model in a static competition environment with a fixed number of players and a fixed price where the customers behave rationally with full information. Particularly, we explore a competitive location routing problem (Comp-LRP) where customers perform routes to collect the demands they have for several competitive products based on a bi-level formulation. Hence, the contribution of this paper is twofold. First, we introduce a competitive location-routing problem and a bi-level model. Second, we prove this Comp-LRP can be solved using a reformulation as a maximal covering location problem (MCLP). We resort to a commercial optimizer to solve the routing problems inside the reformulation and the main MCLP. Computational results on location routing instances adapted from the literature show that using this approach it is possible to solve Comp-LRP instances with up to 200 customers and tens of candidate locations.

■ WD-30

Wednesday, 14:30-16:00 - Virtual Room 30

Disaster and Crisis Management

Stream: Disaster and Crisis Management
Invited session
Chair: *Joana Matos Dias*

1 - Global Pandemics: Analysis and discussion
Khiem Doan, Mo Mansouri

At the writing time of this article, the CoViD-19 pandemic is still being at its highest affection with continuously increasing number of people that are infected and killed by it. We will discuss about the commons and differences between this pandemic and the other ones in the past. The discussion will cover: Source of infection, Reason of pandemic, Reaction of people under pandemic, Solutions and Discussion.

2 - A Robust Optimization Approach for a Fire Suppression Problem
André Bergsten Mendes, Filipe Alvelos

Robust optimization is used to address the problem of assigning fire suppression resources to nodes in a landscape represented by a grid. Given an ignition node, the fire propagates in this grid following the minimum travel time (MTT) principle, which allows determining the fire arrival time at each node by applying the Dijkstra's shortest path algorithm. In order to suppress the fire propagation, resources must be deployed in such a way as to form barriers. We consider that a node is protected when all the required resources are deployed and that a protected node can delay the fire propagation to its unburned adjacent nodes. The number of requested resources depends on node's characteristics that can be considered as certain, such as the fuel, and some other that are uncertain, as the weather conditions (e.g., extremely dry weather and strong winds). Because of the latter, fire suppression at the node may require additional resources. A robust optimization model that minimizes the burned area in the overall landscape under this resource effectiveness uncertainty is proposed. The model integrates the resource allocation decisions with the fire spread behavior. Test instances with up to 400 nodes are solved using Gurobi.

3 - Preparedness for an Earthquake Disaster: Modeling Optimized Deployment of Emergency Treatment Sites
Simona Cohen Kadosh, Zilla Sinuany-Stern, Yuval Bitan

A mass-casualty natural disaster such as an earthquake is a rare unexpected event. The Israeli Ministry of Health defined Emergency Treatment Sites (ETS) as temporary medical facilities for initial treatment of minor injuries. The current "rigid" plan focuses on Main ETSs that will be located at known, predefined fixed locations. Our study evaluated the implementation of a "flexible" plan introducing new Minor ETS that will be located and equipped near destruction sites only after the earthquake happen. Assuming that the evacuation procedure will be by foot, the indexes included the average distance per patient and the proportion of treated casualties. Two main methodologies were used: (1) A mathematical, deterministic, discrete methodology with a hierarchical network design, formulated by mixed integer linear programming (MILP) and goal programming of a Bi-objective function minimizing total distances for locating facilities. (2) A hybrid statistical simulation model combined of discrete events simulation and an agent-based simulation. Adding the Minor ETSs was found to be a robustness solution and equal or better than the rigid mathematic model. It improved the performance of the average distance index in the examined range parameters but decrease the proportion of treated patients in the simulation. The flexible models perform and the simultaneous analysis can be adapted as a decision support tool.

4 - Metric-based Ranking vs. Bi-level Programming: How to Assess Railway Infrastructure Vulnerabilities?
Annunziata Esposito Amideo, Stefano Starita, Maria Paola Scaparra

Railway-based systems are considered as critical infrastructures due to the impact that their malfunctioning could have onto lives of entire communities, starting from the impossibility to commute from home to the workplace (at least before COVID-19!) to more serious issues where a rail/road-based interruption could, for example, lead to the disruption of the food supply chain (e.g., impossibility to deliver food from warehouses to other regions) or halt communications between small towns and big cities where majority of the services are. Hence, it is paramount to work towards the protection of this type of infrastructures. In this paper, we focus on urban rail transit systems and evaluate two different approaches to identify protection strategies: a sequential approach based on vulnerability metrics and an integrated approach based on bi-level programming. Specifically, we display an array of metrics accounting for connectivity, path and flow-related aspects in both a single and combined fashion. This is paired with a bi-level program integrating such aspects. The two approaches have been tested to a Central London Underground study and results are compared accordingly.

■ WD-31

Wednesday, 14:30-16:00 - Virtual Room 31

Design and Analysis of Networks

Stream: Network Optimization
Invited session
Chair: *Austin Benson*

1 - Steiner tree problem with hop constraints: a comparison between node-based and arc-based hop-indexed formulations
Pedro Moura, Luís Gouveia, Bernard Fortz

We study the relation between the linear programming relaxation of two classes of models for the Steiner tree problem with hop constraints. One class is characterized by having hop-indexed arc variables. Although such models have proved to have a very strong linear programming bound, they are not easy to use because of the huge number of variables. This has motivated some studies with models involving fewer variables that use, instead of the hop-indexed arc variables, hop-indexed node variables. In this presentation we contextualize the linear programming relaxation of these node-based models in terms of the linear programming relaxation of known arc-based models. We show that the linear programming relaxation of a general node-based model is implied by the linear programming relaxation of a straightforward arc-based model.

2 - Hypergraph Cuts with Generalized Splitting Functions
Austin Benson

The minimum s-t graph cut is a fundamental combinatorial optimization problem, and graph cuts underlie algorithms throughout applied mathematics. While graphs are a standard model for pairwise relationships, hypergraphs provide the flexibility to model multi-way relationships, and are now a standard model for complex data and systems. However, when generalizing from graphs to hypergraphs, the notion of a "cut hyperedge" is less clear, as a hyperedge's nodes can be split in several ways. Here, we develop a framework for s-t hypergraph cuts by considering various models for penalties at cut hyperedges and use this to develop new local hypergraph clustering algorithms for mining data from social and information networks.

3 - Hypergraph Homophily is Combinatorially Impossible
Nate Veldt, Austin Benson

Homophily, the notion that individuals tend to associate and form connections with similar others, is a widely studied principle in social network analysis. A major motivation of research on homophily in sociology literature is to understand group behavior and group formation. However, since graphs only model pairwise relationship between individuals, graph-based measures of homophily fail to capture certain notions of homophily in multiway interactions. This talk will introduce new hypergraph-based notions of homophily that make it possible to directly quantify homophily in higher-order or group interactions. Using this framework, we show that several intuitive notions of group homophily are in fact combinatorially impossible to realize in practice. For example, in a set of size-3 group interactions between two classes of nodes, it is impossible for both classes to exhibit over-expressed preferences for participating in groups where their class is in the majority. This and related results can be proven by carefully considering primal and dual solutions to linear programs encoding different notions of group homophily. At the same time, our framework reveals other meaningful higher-order notions of homophily that cannot be detected using standard graph-based approaches. This includes examples of gender homophily in co-authorship data and group photo data, and political homophily in legislative bill cosponsorship.

4 - Characterization of QUBO reformulations for the maximum k-colorable subgraph problem
Rodolfo Alexander Quintero Ospina, David E. Bernal, Tamás Terlaky, Luis Zuluaga

Adiabatic quantum computers have shown to outperform classical computers in solving some particular instances of NP-hard problems, like the Graph partitioning problem. To do this, a Quadratic Unconstrained Binary Optimization (QUBO) formulation is needed. Given that many combinatorial problems, particularly NP-hard problems, can be formulated as QUBO instances, the interest in getting implementable QUBO formulations of such problems has grown in recent years. In this presentation, we will focus on the QUBO formulations of the independent set and the maximum k-colorable subgraph problems, and some possible limitations to implement them in quantum computers.

■ WD-32

Wednesday, 14:30-16:00 - Virtual Room 32

Robust ordinal regression

Stream: Multiple Criteria Decision Analysis
Invited session
Chair: *Salvatore Greco*

1 - Multicriteria decision aiding using representative value functions
Salvatore Greco, Sally Giuseppe Arcidiacono, Salvatore Corrente

A representative value function is a compatible value function that highlights necessary and possible preferences in robust ordinal regression. A representative value function can support the decision maker to understand the recommendation formulated in terms of necessary and possible preference relations. We reconsider the concept of representative value functions in decision aiding procedures, taking into account some considerations based on decision psychology.

2 - Scoring alternatives from pairwise winning indices
Salvatore Corrente, Sally Giuseppe Arcidiacono, Salvatore Greco

In this paper we revise in a critical way the procedures used to to summarize the pairwise winning indices results. Pairwise winning indices are provided by Stochastic Multicriteria Acceptability Analysis and they represent the frequency with which an alternative is preferred to another on the basis of same sampled instances of the assumed preference model compatible with the preferences provided by the Decision Maker. The scoring procedures provide a single value to each alternative being representative of the goodness of the alternative itself taking into account the frequency with which it is preferred to the others or, vice versa, the others are preferred to it. The score given to the alternatives gives the possibility to rank them from the best to the worst. A comparison between different methods is performed to look at their strong and weak points.

3 - Multicriteria decision aiding using probability distribution in the space of compatible value functions
Sally Giuseppe Arcidiacono, Salvatore Greco, Salvatore Corrente

Robust ordinal regression is based on the idea that there is a plurality of value functions compatible with the preferences expressed by the decision maker. Originally, the set of compatible value functions was used to define the necessary and possible preference relations holding when the preference between two alternatives holds for all value functions or for at least one of them, respectively. After, probability of preference and probability of getting a certain rank position taking randomly a compatible value function was introduced by Stochastic Multicriteria Acceptability Analysis. Recently a methodology to build a probability distribution in the space of value function was proposed. In view of this, we aim to investigate basic principles and main aspects of a multicriteria decision aiding procedure based on the probability distribution in the space of compatible value functions.

■ WD-33

Wednesday, 14:30-16:00 - Virtual Room 33

Advanced Disease Policy Modelling and Decision Support

Stream: ORAHS: OR in Health and Healthcare
Invited session
Chair: *Marion Rauner*
Chair: *Margaret L. Brandeau*

1 - Agent-based evolving network modeling- a new simulation technique for study of diseases spread over complex networks at low prevalence
Chaitra Gopalappa

We present the agent-based evolving network modeling (ABENM), a new technique for simulating epidemic outbreaks over complex contact networks at low prevalence. As current agent-based network modeling (ABNM) consists of simulating the network of all infected and susceptible persons, they are computationally infeasible for studying certain questions at low prevalence, including endemic diseases such as HIV and TB, or in the early stages of newly emerging disease outbreaks such as COVID-19, Ebola, and SARS. ABENM simulates only infected persons and their immediate contacts as agents in a network and all other susceptible persons as compartmental model. New algorithms, using concepts from graph theory, stochastic processes, and optimization, maintain the network dynamics over time, including evolving the network, i.e., transitioning contacts of newly infected persons from compartmental to the network. We apply ABENM to HIV where contacts follow a scale-free network, for potential use for cluster analyses in conjunction with molecular cluster detection and response to new disease outbreaks. Molecular clusters are groups of HIV infections that are genetically similar, indicating rapid HIV transmission and where interventions are needed to prevent future new infections. As surveillance data are only available for cases that are diagnosed and reported, a model is a critical tool to understand the true size of clusters and assess key questions to inform effective response strategies.

2 - Early Detection of COVID-19 Outbreaks Using Human Mobility Data
Margaret L. Brandeau, Grace Guan, Yotam Dery, Matan Yechezkel, Yuval Foox, Irad Ben-Gal, Dan Yamin

Social distancing measures can play a key role in reducing the spread of COVID-19. To appropriately target the timing, location, and severity of measures intended to encourage social distancing, it is essential to be able to predict when and where outbreaks will occur, and how severe they will be. We use machine learning with anonymized health data and cell phone mobility data from Israel from March-December 2020 to develop models for predicting daily active and new cases of COVID-19 and the COVID-19 test positivity rate over the next 7 days for all geographic regions in Israel. We combine these predictions with a five-tier categorization system to predict the severity of COVID-19 in each region over the next week. We find that human mobility data can improve prediction of when and where COVID-19 outbreaks are likely to occur. These predictions can be used to appropriately target the timing, location, and severity of mobility restrictions intended to reduce COVID-19 spread.

3 - Maximal covering location problem in Mexico to allocate COVID-19 test.
Salvador Vicencio-Medina, Yasmin Rios-Solis

In Mexico, the hospitals were classified as COVID by the government and only them are able to receive tests to detect COVID-19. Besides, the COVID-19 tests are scarce and the most of them are sent to the most important cities. Consequently, cities or small towns may be at high risk since they do not have a near hospital with COVID-19 tests.

The objective of this work is to maximize the coverture of Mexican population considering the number of COVID hospitals per state, the number of municipalities per state, the poverty level per municipality, the death people by COVID-19, the detected persons contaminated per municipality. Besides, we have considered that the COVID-19 tests given by the government are proportional to the number of people that live in each state.

We use the Maximal Covering Location Problem where not only the coverture by the hospitals is considered but the accessibility of the persons to reach a COVID-19 hospital. In the MCLP, a set of facilities where n hospitals must be allocated with COVID-19 tests to cover and set of demand zones (municipalities) are given.

Our model considers mobile hospitals (i.e., ambulances), that is, the COVID hospitals with allocated tests could send mobile hospitals to close municipalities to increase the coverage. To evaluate the model developed, we have created 3 different class of instances. The experimental results show that the use of mobile hospitals has a large impact in the coverage.

4 - Production function of death: Performance assessment of the English NHS hospitals during the COVID-19 pandemic
Sheng Dai, Timo Kuosmanen, Aaron Tan

COVID-19 is an unprecedent virus that had killed more than 2 million people around the world by January 2020. Thus far there has been little effort to examine performance of hospitals that are in the forefront in the battle against the pandemic. In this paper we propose a novel approach to assess the effectiveness of hospitals in saving lives and estimate the production function of COVID-19 caused death among hospital inpatients, incorporating contextual variables to the convex quantile regression approach. We propose a novel approach to utilize Heckman's two-stage approach to correct for the bias caused by zero-valued observations. Data of 187 hospitals in England over a 35-week period from April to December 2020 is divided in two sub-periods to compare the structural differences between the first and second waves of the pandemic. Our results indicate that expected mortality of inpatients decreased from the first wave to the second one. While there was significant performance improvement during the first wave, however, learning by doing was offset by the new mutated virus straits during the second wave. While the elderly patients were at significantly higher risk during the first wave, their expected mortality rate did not significantly differ from that of the general population during the second wave. Finally, there are significant regional differences in hospital performance, but the performance gaps decreased as the pandemic moved from the first wave to the second one.

■ WD-34

Wednesday, 14:30-16:00 - Virtual Room 34

Multiobjective Combinatorial Optimization

Stream: Combinatorial Optimization
Invited session
Chair: *Matthias Ehrgott*

1 - A Simple, Efficient and Versatile Objective Space Algorithm for Multiobjective Integer Programming
Kathrin Klamroth, Kerstin Daechert, Tino Fleuren

We combine recent results on objective space methods to formulate a unified and versatile generic algorithm for optimization problems with an arbitrary number of objectives. The algorithm is generic in the sense that it builds a framework for efficiently handling generated solutions. It can be combined in a modular way with any scalarization that is suited to get into non-convex parts of the nondominated set.

Efficient solutions are generated iteratively by solving appropriate scalarized single objective optimization problems using readily available IP solvers. While keeping the number of solver calls small by avoiding redundancies, the strength of single-objective solvers leads to an efficient strategy for the generation of the complete efficient set of multiobjective integer programming problems with any number of objective functions.

The advantages of this generic approach are confirmed by extensive numerical tests including comparisons with state-of-the-art algorithms for which open-source implementations exist. Besides the evaluation of knapsack and assignment instances from the literature, we also present new instances with up to 10 objectives. Also for these high-dimensional instances, our generic framework outperforms existing approaches.

2 - A new label setting framework for the Multiobjective Shortest Path problem.
Pedro Maristany de las Casas, Ralf Borndörfer, Antonio Sedeño-Noda

In this talk, we discuss a new Multiobjective Dijkstra Algorithm for the exact and approximate versions of the Multiobjective Shortest Path (MOSP) problem that reduces known complexity bounds of MOSP problems by simplifying the label handling during the algorithm. The main idea is to admit at most one path per node in the priority queue, hence restricting its size to the problem's input size, causing more efficient heap operations. Moreover, different FPTAS for MOSP problems have been presented in the literature in recent years. They are based on a disjunctive subdivision of the outcome space into polynomially many cells. If the output is guaranteed to hold at most one path per cell, this technique can be used to construct FPTAS for MOSP. We discuss how this generic procedure can be also used in our new Multiobjective Dijkstra Algorithm to obtain a new FPTAS with improved complexity bounds. One last contribution is the study of the correctness of both the exact and the approximate versions of our algorithms in the presence of dynamic arc costs. We show that under mild assumptions on the structure of the arc cost functions, we can guarantee the correctness also in this scenario. Our findings are supported by extensive computational experiments whose results will be presented at the end of the talk.

3 - Multi-objective Optimization for Product Line Design
Konstantinos Zervoudakis, Stelios Tsafarakis

Introducing new products has an important role in sustainability and profitability of a firm. The Product Line Design (PLD) problem is a key decision area that product managers have to deal with in the early stages of product development, to estimate the potential success of a product line. Even though several objectives may be simultaneously pursued during the product configuration process, most reported studies have focused on single-objective optimization such as maximizing market share or profit or minimizing cost. In this research, we address the PLD problem by taking into account more than one objectives, using two variants of Multiobjective Particle Swarm Optimization. The two proposed approaches are fully adapted to the problem using a Fuzzy Logic Self-Tuning process, each one obtaining a set of nondominated design alternatives (solutions). Consequently, product managers are provided with a better tradeoff among various objectives. The performance of the multi-objective PSO variants for PLD is compared to those of state-of-the-art solvers when it comes to multiobjective optimization.

4 - A New Algorithm For Mixed Integer Bi-Linear Maximum Multiplicative Programs
Hadi Charkhgard, Vahid Mahmoodian, Iman Dayarian

This study introduces a branch-and-bound algorithm to solve Mixed-Integer Bi-Linear Maximum Multiplicative Programs (MIBL-MMPs). This class of optimization problems arises in many applications such as finding Nash bargaining solution (Nash social welfare optimization), capacity allocation market, reliability optimization, etc. The proposed algorithm applies multi-objective optimization principles to solve MIBL-MMPs exploiting a special characteristic in these problems. That is, taking each multiplicative term in the objective function as a dummy objective function, the projection of an optimal solution of MIBL-MMPs is a nondominated point in the space of dummy objectives. Moreover, several enhancements are applied and adjusted to tighten the bounds and improve the performance of the algorithm. The performance of the algorithm is investigated by 400 randomly generated sample instances of MIBL-MMPs. The obtained result is compared against the outputs of the mixed integer Second Order Cone Programming (SOCP) solver in CPLEX and a state-of-art algorithm in the literature for this problem. Our analysis on this comparison shows that the proposed algorithm outperforms the fastest existing method, i.e., the SOCP solver, by a factor of 6.54 on average.

■ WD-35

Wednesday, 14:30-16:00 - Virtual Room 35

Queues with Strategic Customers in Public Services

Stream: Queues with Strategic Customers
Invited session
Chair: *Tuan Phung-Duc*

1 - Equilibria of supply and demand in double-ended queueing systems
Hung Q. Nguyen, Tuan Phung-Duc

This paper considers a scenario where either/both of the supply side or/and demand side adopt strategic behaviors in double-ended queueing systems, with the attempt to find equilibria in the cases where system states are observable or unobservable. In the observable case, we found that the strategic behaviors of buyers and sellers do not affect each other, so the equilibria are easily derived. However, in the unobservable case, the strategy of buyers not only affects that of the following ones, but also affect sellers' strategic behaviors, and vice versa; thereby making it more complicated to derive system equilibria. Also, we found that some equilibria only occur under some special conditions. Finally, we propose a simple pricing mechanism such that even when both buyers and sellers are strategic, they are definitely willing to join the system.

2 - Queueing Analysis of Car/Ride-Share System
Ayane Nakamura, Tuan Phung-Duc, Hiroyasu Ando

In this presentation, we discuss Car/Ride-Share (CRS), which is a novel concept of transportation service aiming at reducing the uneven distribution of cars in traditional carsharing service and the congestion of people. CRS is defined as a system where people ride together a private car, which is provided by car providers for receiving financial incentives. Therefore, CRS is regarded as a mixed system of Car-Share and Ride-Share. We consider a scenario where CRS is introduced between a station and a spot (e.g., university, company etc.) considering the state of the road between two points. To make the system easier to analyze, we present an approximation model. By some numerical experiments, we show that the approximation model shows highly accurate results in a short calculation time compared to the simulation. Also, we present some useful results; CRS is effective from the perspective of the throughput, however, CRS becomes ineffective when the road is highly congested from the perspective of the traveling time, etc. Besides, we also discuss the price mechanism of CRS such that all system participants (i.e., the bus company, the car providers and the customers) benefit compared to before the introduction of CRS. By some numerical experiments, we show the interesting features of the executable fee range of CRS depending on the various parameters (e.g., the arrival rate of customers at both side).

3 - Optimal Capacity Planning for Cloud Service Providers with Periodic, Time-Varying Demand
Eugene Furman

We determine the jointly optimal service capacity and retrial intervals between unsuccessful service attempts for a major provider of cloud computing services. Allocating sufficient capacity to cloud services is a challenging task because demand is time-varying. Thus, most firms have been expanding their capacity with little regard to the consequences associated with idle resources, such as excessive energy consumption and excess costs. We model the system as a multi-station queueing network where the arrival rate of jobs is time-varying and the servers represent CPU cores. Jobs are infinitely impatient and those that are not immediately serviced may retry several times before permanently abandoning the system. We introduce an offered load approximation that allows us to construct a recursive representation of the offered load function which describes the fluid dynamics of the system. We develop a calculus-of-variation approach to minimize the total functional variation of the constructed offered load function. We show that an optimal policy can be efficiently obtained and prove that it is similar to maximizing the penalized system throughput.

4 - Rational joining behavior in a queueing system with abandonments
Michal Benelli

We consider individually and socially-optimal joining behavior in a first-come first-served M/M/1 queueing system where a customer's need for service may expire after an exponentially distributed length of time. We show that the individual behavior is independent of the rate of abandonment. We use the fact that the individual behavior in a last-come first-served M/M/1 queue is socially-optimal to compute the socially-optimal threshold.

■ WD-36

Wednesday, 14:30-16:00 - Virtual Room 36

Game Theory, Solutions and Structures VI

Stream: Game Theory, Solutions and Structures
Invited session
Chair: *Marco Dall'Aglio*

1 - On majority voting rules
Dani Samaniego, Josep Freixas

This work considers voting situations in which voters play a symmetrical role; decisions are binary and are taken by majority rule. As it happens in reality, voters can vote in favor of the motion submitted to vote, against, abstain or not vote and only valid votes cast are taken into account. The only necessary requirement for a majority rule is that the number of votes in favor of the motion submitted to vote exceeds the number of votes against it. It is, therefore, a general rule that contains, among others, the unanimity rule, the absolute majority rule and the simple majority rule.

The study carried out aims to determine the range of possibilities that these voting rules offer. To this purpose, we enumerate them as a function of the number of voters. Given that its growth is exponential, we consider some parameters associated to each majority rule that allow determining the most suitable of them. Among these parameters, we highlight the guaranteed representativeness, the legitimacy and the plurality of each rule.

2 - Solidarity power indices
Izabella Stach, Cesarino Bertini, Jacek Mercik

In this work we concern some measures for diving a (public) good, budget or an amount among members with different quotas of participation in a binary decision-making process. A main idea of such measures is that it should have ingredients of solidarity with those who have a weak quota of participation in the process. The measure seems appropriate for deals that require solidarity, which contrasts with the classical power indices.

3 - Minimal winning coalitions and orders of criticality
Marco Dall'Aglio, Michele Aleandri, Vito Fragnelli, Stefano Moretti

We analyze the order of criticality in simple games, under the light of minimal winning coalitions. The order of criticality of a player in a simple game is based on the minimal number of other players that have to join that player in question, so that the coalition becomes pivotal. We show that this definition can be formulated referring to the cardinality of the minimal blocking coalitions or minimal hitting sets for the family of minimal winning coalitions; moreover, the blocking coalitions are related to the winning coalitions of the dual game. Finally, we propose to rank all the players lexicographically accounting the number of coalitions for which they are critical of each order, and we characterize this ranking using four independent axioms.

■ WD-37

Wednesday, 14:30-16:00 - Virtual Room 37

Routing problems with loading constraints

Stream: Cutting and Packing
Invited session
Chair: *Jean-François Côté*

1 - A new comprehensive approach for choosing proper load carriers
Dominik Berbig, Christoph Schrimpf

The last months have shown how important efficient processes and material flows are. Amongst others, efficiency requires comprehensive analyses taking also possibly inconspicuous things into consideration. Let's take material supply of production areas as an example: Here, it is crucial to choose the adequate load carrier for every single part number. The larger the carrier is, the larger is the required space, the number of contained pieces and finally fixed capital. The smaller it is, the higher is the necessary transportation frequency. These are only some dependencies showing that choosing efficient load carriers is subject to many parameters. Even if some efforts have been undertaken during the last years, still this choice is mostly based on size only ignoring other aspects. Thus, we have developed and improved a two-step approach combining comprehensive TCO analyses and optimization models. The first step, a comprehensive TCO consideration for each individual part number, incorporates relevant influencing factors (personal cost, equipment, space...) as well as required process steps (picking, transportation, storing...). Subsequently, this TCO model is integrated into an optimization model to be able to choose optimum load carriers for a certain set of different parts in parallel. The results of the TCO model as well as the current status of the applicability and enhancement of the optimization model are shown in our paper.

2 - An Open-Source Visualization Tool for VRP and 3D-CLP
Corinna Krebs

The optimization of cargo loading and transportation of goods are two highly considered NP-hard optimization problems. The combination of both, namely the 3L-CVRP, has attracted increasingly interest in the past decades. Hereby, three-dimensional cuboid items have to be transported from a central depot to a given set of customers using a homogeneous fleet of vehicles. Each route must be provided with a feasible packing plan taking various constraints into account. In one extension, time windows at the depot and at customers are additionally considered (3L-VRPTW).

In this presentation, an open-source visualization tool for 3L-CVRP and 3L-VRPTW solutions is demonstrated. In the vehicle routing view, the tour plan and the corresponding schedule are displayed. In the packing plan view, the position of each item in the cargo space is visualized. It is also possible to use the tool solely for one optimization problem (e.g. vehicle routing or 3D container loading problem).

Moreover, the tool checks the feasibility of the solutions and indicates violated constraints by using an integration with an already published open-source solution validator. The source-code will be available at Github.

3 - The Transportation Problem with Packing Constraints
Tulay Flamand, Mohamed Haouari, Manuel Iori

We address a novel class of the transportation problem, where there are several types of commodities at multiple supply nodes to be delivered to multiple demand nodes. Commodities are delivered in multiple trips using a set of transportation modes, where each commodity accommodates a specific weight on each transportation mode. Therefore, the model has a packing constraint associated with the total capacity of each transportation mode. We propose an effective column generation methodology to find a lower bound for this challenging problem and discuss our computational results.

■ WD-38

Wednesday, 14:30-16:00 - Virtual Room 38

Pricing, Delivery Time, and Competition

Stream: Operations/Marketing Interface
Invited session
Chair: *Kathryn E. Stecke*
Chair: *Xuying Zhao*

1 - Alliance Formation Among Competitors: Impact of Limited Capacity and Loyal Segments
Derui Wang, Xiaole Wu, Christopher Tang, Yue Dai

We study potential alliance formation among three competing firms with asymmetric capacity: One large firm has ample capacity, and two small firms have limited capacity. Each firm can either operate independently or form an alliance with another firm. Due to antitrust laws, an alliance of all three firms is not permitted. When a two-firm alliance is formed, the alliance and the remaining independent firm use prices and the resulting capacity to capture their own "loyal buyers" and compete for price-sensitive "disloyal switchers". We first derive and compare equilibrium profits under different alliance structures in the base model where the size of loyal buyers for different firms is symmetric. By considering a standard equilibrium concept, we find that either no alliance will be formed or the large firm will form a "mixed" alliance with a small firm under conditions pertaining to the sizes of each firm's capacity and loyal buyers. We explain how the equilibrium alliance structure is driven by the "price effect" and the "demand effect". Specifically, the mixed alliance structure dominates when the price effect overshadows the demand effect, and no alliance will be formed when the demand effect outweighs the price effect. We also extend our base model to the case when the large firm has more loyal buyers than the small ones, and show that a "small" alliance consisting of two small firms can emerge as the dominant alliance structure on some occasions.

2 - Optimal Pricing of Points in Points Plus Cash Reward Programs
Ricardo Montoya

Customers in Reward Programs (RPs) typically accumulate points for their purchases that can be redeemed later for rewards. Recently, some RPs offer the option of combining a customer's points with cash to redeem them for products in a Points Plus Cash (PPC) frame. The price of these points needs to be determined by the company considering various factors such as the consumers' consumption heterogeneity and willingness to pay for the points, the value of the product, and the cost of that product. The goal of this research is to determine the optimal price in a PPC scheme taking these factors into account. The proposed framework considers differences in consumption rates and product valuations by customers that allow a profit-maximizing firm to determine the optimal dynamic price. Our main result characterizes the optimal price as a function of the time remaining to the end of the selling horizon. We show that the price increases in time and decreases regarding the number of points required to be redeemed for the product. The optimal pricing uncovers three types of customers buying at different times during the selling horizon. We use the developed framework to compare the proposed pricing strategy to other pricing options such as constant pricing and also to explore extensions to our basic model.

3 - Time-based Pricing at Grocery Stores? Transitioning Strategies under Retail Competition and Congestion Externality
Dongyuan Zhan, Christopher Tang, Onesun Yoo

The COVID pandemic has underscored "congestion disutility" in the context of consumers shopping at brick-and-mortar stores. Enabled by emerging technologies such as smart shelves and electronic shelf labels, retailers have begun to contemplate time-based pricing. This study examines whether (and, if so, how) retailers selling essential items should transition to time-based pricing, or charging higher prices during peak hours in order to smooth demand and reduce the store congestion. We incorporate consumers' congestion disutility in a two-stage dynamic game between two retailers. Specifically, two types of transition are considered: "immediate" and "cautious". In the latter, rather than transitioning immediately, retailers set a "uniform" regular price during an initial phase, and then implement higher peak-hour prices in a later phase while maintaining the regular price during normal hours. We find that, when the retailers are myopic, both choose an "immediate transition"; this choice does not affect consumer welfare. Otherwise, depending on the extent of retailer myopia and of consumers' aversion to congestion, there can be an equilibrium when both retailers choose a "cautious transition" or when one chooses an "immediate transition" while the other chooses a "cautious transition"; each of these equilibria may be detrimental to consumer welfare. However, demand smoothing is achieved irrespective of the retailer transition strategies.

4 - The impact of sustainability information disclosure on consumer choice of delivery time in online shopping
Viet Nguyen, Sander De Leeuw

As a result of consumer demand for short delivery time, express deliveries such as same-day or next-day have been increasingly adopted by e-commerce companies. Compared to slower options (e.g. delivery in 3 days), these express options are not only more costly to retailers but also more intensive with regard to environmental impact (e.g., increased carbon emission) and social impact (e.g., worsened delivery driver's wellbeing). Whilst significant practice and research effort has been dedicated to making delivery operations more sustainable, consumers are mostly unaware of the sustainability consequences of express delivery. Positioned at the marketing-operations interface, we take a proactive approach that aims to steer consumer behaviour for better managing the last-mile delivery service. We investigate the impact of sustainability information disclosure on consumer choice of delivery time: are well-informed consumers willing to wait longer for their deliveries? Through of a series of choice experiments with participants from NL (n = 348) and UK (n = 1387) we find that disclosing environmental or social sustainability information associated with delivery options significantly increases consumer choice of longer delivery time. We further address the relationship between consumers' concern for sustainability (psychology) and the impact of information disclosure on their choices of delivery (behaviour).

■ WD-39

Wednesday, 14:30-16:00 - Virtual Room 39

Emerging Research on Education, Competences and Labor Markets 1

Stream: Emerging Research on Education, Competences and Labor Markets
Invited session
Chair: *Małgorzata Spychała*
Chair: *Marek Goliński*

1 - Statistical methods of verification of the candidate's self-esteem
Małgorzata Spychała, Magdalena Graczyk-Kucharska, Marek Goliński, Maciej Szafranski

The scientific study presents the results of analyzes concerning laboratories carried out for students studying in the profession of a mechatronics technician. Two main research problems are considered. The first is the effectiveness of laboratories, measured as the difference in the results obtained in the competency tests before and after the end of the laboratories. The second aspect examined is the credibility of the students' self-assessment, which was compared with the results of competency tests. Data collected after the conducted laboratories are treated as sample data. On the basis of the data from the sample, statistical inference was carried out, the aim of which was to formulate some general conclusions regarding the development of specific competences and the level of self-esteem among students not only in the studied sample, but in the entire population. The significance test verified the hypothesis as to whether the laboratories caused an increase in competences. It was checked whether the self-esteem of women and men differed from each other, and a test of the significance of the equality of Welch's T means for two independent samples was performed. The significance tests carried out proved that for all competences developed during the laboratories, the self-assessment of students is lower than the results of the final test. This means that the students honestly assess their competences.

2 - Predicting employees' turnover by analytic hierarchy process method

Ivana Kovacevic, Ognjen Pantelic, Jelena Anđelković Labrović

Employees' turnover is an issue for organizations due to the costs in time and money to replace them, especially when good employees are leaving (dysfunctional turnover). Although behind the employees 'intentions to leave organization usually lies dissatisfaction reasons for turnover are various, as well as predictors. Some predictors are external (opportunities), while others are internal and organizational. Nevertheless, researchers found that potential alternatives weight less compared to affective aspects of current job situation perception and commitment. First step into the turnover prevention is recognizing dissatisfied employees, which is not easy task in large organizations. By identifying those with high risk of turnover there is a possibility to prevent automotive company of 665 employees varying in age, gender, years of tenure and work positions, from losing valuable employees by recognizing their intentions/dissatisfaction on time. Our idea is to implement Analytic Hierarchy Process Method to predict potential turnover, with criteria considering objective characteristics of work measured by Motivating Potential Score (MPS), employees' motivation calculated through Relative Autonomy Index (RIA), needs and aspirations, and work satisfaction (with supervisors, organization as whole, organizational justice, and need satisfaction provided in organizational context.

3 - Determinants of Female Representation on Corporate Boards: How to Treat a Selection Bias?

Vladlena Prysyazhna, Sascha H. Moells

Female representation on corporate boards has increasingly become an important issue in corporate governance regulation and is also intensively being addressed by academic scholars in recent decades. From a methodological standpoint, attempts to investigate the determinants of female representation on boards are faced with the problem of non-existing female directors in a large fraction of firms. Thus, analyses have to deal with a heavily censored dependent variable, while the derived results might suffer from a sample selection bias. In our paper we address this problem by applying a Tobit regression to account for the (left-)censored dependent variable. Our study is based on a sample referring to each of the biggest 100 publicly traded corporations of 15 industrialized countries belonging to different corporate governance systems (Exit, Voice, Loyalty) covering the years 2010 and 2015, resulting in about 1500 observations per year. Firm-specific data on female representation on management boards, supervisory boards and the board of directors as well as other corporate governance attributes are all hand-collected and derived for both reference years based on annual documents published by the firms. By using a comprehensive sample on female representation on boards as well as an advanced methodological approach, we are able to overcome shortcomings of previous work and thus are able to improve insights in the determinants of board diversity.

■ WD-42

Wednesday, 14:30-16:00 - Virtual Room 42

Advances in Dynamic Programming

Stream: Stochastic Dynamic Programming
Invited session
Chair: *Jefferson Huang*

1 - Slow service-times and high quality of service vs. fast service-times and time-deteriorating quality of service - a trade-off using Markov Decision Processes

Mihaela Mitici

In many applications, a natural trade-off emerges between offering a service fast, with a slightly outdated level of quality, and taking more time to deliver the service, but guaranteeing a high level of service. Take, for example, the case of retrieving data on the quality of the air in a building. Should one request the most up-to-date, real-time data that sensors can gather, then some delay should be expected. Otherwise, already available, yet not the most up-to-date data can be provided fast. The question is how much should one compromise on the quality of the data, and when should a slow service be preferred. We formulate the problem of trading-off between slow service-times and high quality of service vs. fast service-times and deteriorating quality of service as a discrete-time Markov process. Here, we consider that the quality of the service deteriorates linearly over time. We obtain an optimal decision policy that manages to trade-off between slow service-high quality strategies and fast service-outdates quality strategies. The performance of such optimal policies is compared against slow service-only and fast service-only policies, for which analytical expressions are obtained. Overall, this study proposes a methodology to obtain optimal decision strategies that balance conflicting objectives.

2 - A comparison of algorithms for learning the Whittle index for restless bandits with unknown parameters

Lachlan Gibson, Peter Jacko, Yoni Nazarathy

The well known restless bandits problem deals with the control of a constrained system where limited resources are to be applied to bandits that evolve according to Markovian dynamics. For this, Whittle index based control policies are known to have favourable properties but require knowledge of the underlying transition probabilities. Recently, several algorithms for learning the Whittle index have been proposed, similarly to classic Q-learning algorithms, but considering the index as a learned parameter. While novel, the performance of such algorithms on a wide range of problems is still not well understood. For this, we carry out an investigation comparing existing and new proposed algorithms. We present both empirical simulation results and analytic insights.

3 - Solvable Markov Decision Processes with Incomplete Information

Eugene Feinberg, Pavlo Kasyanov, Michael Zgurovsky

We introduce natural conditions for the existence of optimal policies for a Markov decision process with incomplete information (MDPII) and with expected total cost criteria. MDPII is the classic model of a controlled stochastic process with incomplete state observations which is more general than models of a Partially Observable Markov Decision Processes (POMDPs). For MDPII we introduce the notion of a semi-uniform Feller transition probability, which is stronger than the notion of a weakly continuous transition probability. We show that an MDPII has a semi-uniform Feller transition probability if and only if the corresponding belief MDP also has a semi-uniform Feller transition probability. This fact has several corollaries. In particular, it implies all known sufficient conditions for the existence of optimal policies for POMDPs with expected total costs.

4 - Bandit Algorithms for Data-Driven Resolution/Field-of-View Tradeoffs in Multi-Mode Sensing and Intelligence Collection

Jefferson Huang

We consider how different sensing/collection modes should be employed when the operator needs to trade off the resolution of the selected sensor, versus its field-of-view (FOV). Motivating application areas include the routing of imagery assets, and cyber intrusion contexts where intelligence is distributed over a computer network. We focus on the particular case where, for each glimpse, the operator can either use a high-resolution (i.e., low noise) sensor to observe a particular source, or use a lower-resolution (i.e., high noise) sensor to observe all sources simultaneously. Data-driven algorithms based on modeling the operator's sequential decision-making problem as a type of multi-armed bandit problem are presented for judiciously determining which mode to use, given what has been observed so far.

■ WD-45

Wednesday, 14:30-16:00 - Virtual Room 45

Covid-19 Pandemic in Retail & Mobility

Stream: Demand and Supply in Consumer Goods and Retail
Invited session
Chair: *Elisabeth Obermair*

1 - Challenges and Opportunities in disruptive Times of Grocery Retailing: Lessons Learned from the Covid-19 Pandemic
Elisabeth Obermair, Andreas Holzapfel, Heinrich Kuhn, Michael Sternbeck

The Covid-19 pandemic caused huge uncertainties in supply chains and put high pressure on grocery retailers. Especially in the initial phase of the pandemic, grocery retailers were faced with panic shopping and high demand for non-perishable groceries. We applied an embedded multiple case study to analyze the impact of the pandemic on grocery retail logistics. Within the study we focus on the German market as the occurrence of infections and government strategies created country-specific conditions. Within each case, we focused on the following planning and execution areas: procurement, warehousing, disposition, transport and store management. Our contribution highlights the challenges and opportunities that grocery retailers faced in the initial phase of the Covid-19 pandemic. Weaknesses in the standard business revealed by the pandemic are identified. From this, we derive four development areas for grocery retail logistics: developing the online channel, changing behavioral disposition, digitalizing the supply chain and improving the agility of the supply chain. The results of the study can be used to develop new and enhance existing decision support models in grocery retailing.

2 - Identifying Covid-19 lockdown net effects on the demand of grocery store sales incorporating trend, cycles, seasonality and calendric effects
Philipp Reinhard, Ulrich Küsters, Michael Sternbeck, Heinrich Kuhn

With the outbreak of the Covid-19 pandemic, a significant change in consumer behavior can be observed. This study analyses the changes in demand for 4,000 time series from a grocery store chain with over 300 stores. We focus on the period from 1 February 2020 to 31 April 2020, which includes the beginning of the pandemic and the first lockdown in Bavaria.

Daily demand series strongly contaminated with special day effects were used to identify the net change of consumer behavior due to Covid. These non-equidistant time series were available for Bavaria, districts and stores across different product groups. Store and district-specific series were available for two Covid free years only. To identify the Covid net effects, we applied a sequential procedure. First, we identified trend, seasonal cycles, public holidays, special days, and weekday effects using longer series over ten years which were available only as aggregates for Bavaria. Second, we embed these effects partially into the store specific time series truncated to the Covid free period up to 31 January 2020. Third, the cumulated Covid free period effects were used to identify the net effects within the lockdown period. This yields a separation of regular effects from first panic shopping effects. Our method allows the assessment of the district and product group-specific changes in consumer behavior due to Covid-19 effects and lockdown measures.

3 - Investigating the impact of COVID-19 pandemic in supply chain operations: Survey findings from Greece
Vasileios Zeimpekis, Anastasios Gialos

The COVID-19 outbreak has exposed the vulnerability of global supply chains and local economies to exogenous shocks. It has also accelerated some existing emerging trends in consumption patterns, such as the shift to e-commerce, as much as 5 years into the future. In Greece, the pandemic has seriously affected local supply chain networks and various inefficiencies have been observed both in supply chain planning (e.g., demand planning) as well as in supply chain execution (e.g., last mile delivery). At the same time various opportunities have arisen since COVID-19 accelerated the digital transformation of logistics processes as well as the adoption of new business models and systems for increased customer experience. The main aim of this paper is to present the findings of a survey that was conducted in Greece in 2020, aiming at mapping the impact as well as the challenges that the Greek supply chain sector faced during the pandemic. The survey describes the main consequences in the daily operation of 125 companies focusing on the outcomes of COVID-19 in supply chain processes. Furthermore, the survey presents the actions that Greek companies were willing to take to transform their supply chain networks to resilient and agile ones.

4 - Analysis of demand pattern variations and functional changes in mobility due to Covid-19 pandemic
Maria Sartzetaki, Dimitrios Dimitriou, Aristi Karagkouni

The outbreak of the novel coronavirus Sars-Cov-2, also known as COVID-19 is already considered as one of the greatest shocks in the last 60 years, strong enough to modify future needs and social values. Especially for Generation Z, those born between 1995-2009, COVID-19 will be the crisis of their generation, as it comes at a critical time as older Gen Zers are finishing education and entering the workforce. Several of the changes in personal priorities may persist in time, even after the eventual recovery. Traffic and transport operations are a reflection of the social and economic activity. During the pandemic, the measures applied in order to limit the propagation of the disease resulted in extensive mobility restrictions with a pronounced impact on most transport modes. The path to recovery for the transport sector depends on the strategy that will be followed in terms of the gradual relaxation of restrictions, the general population vaccination evolution and the future operational rules that will affect the supply side and the rate of improvement of the general economic conditions. This paper deals with the evaluation of the mobility restrictions' effects on daily urban commuting but also on long-distance travel planning during the first year of the pandemic outbreak. The research outputs based on the results of a questionnaire survey addressed to Generation Z, providing results about changes in mobility patterns as well as the planning of long-distance travel.

■ WD-46

Wednesday, 14:30-16:00 - Virtual Room 46

Supply-side Flexibility in Revenue Management

Stream: Revenue Management and Pricing
Invited session
Chair: *Claudius Steinhardt*

1 - How much to tell your customer? - A survey of three perspectives on selling strategies with opaque and flexible products (incompletely specified products)
Jochen Gönsch

Today's technology facilitates new selling strategies. One increasingly popular strategy uses incompletely specified products (ICSPs). The seller retains the right to specify some details of the product or service after the sale. The selling strategies' main advantages are an additional dimension for market segmentation and operational flexibility due to supply-side substitution possibilities. Since the strategy became popular with Priceline and Hotwire in the travel industry, it has increasingly been adopted by other industries with stochastic demand and limited capacity as well. It is actively researched from the perspectives of strategic operations management, empirics, and revenue management. This talk first describes the application of ICSPs in practice. Then, we introduce the different research communities that are active in this field and relate the terminology they use (e.g. opaque selling, flexible products, upgrades). The main part is an exhaustive review of the literature on selling ICSPs from the different perspectives. We see that strategic operations management has described advantages of ICSPs over other strategies in a variety of settings, but also identified countervailing effects. Today, empirical research is confined to hotels and airlines and largely disconnected from the other perspectives. Operational papers are ample, but mostly concerned with the availability of ICSPs. Research on operational (dynamic) pricing is surprisingly scarce.

2 - Upselling based on Customer Choice Behaviour - Does Tracking Offer Sets Pay Off?
Davina Hartmann, Jochen Gönsch, Claudius Steinhardt, Robert Klein

After a customer has bought an economy airline ticket, the airline offers him/her an upsell for a certain price after the booking horizon, e.g. a seat in the business class for additional EUR 50. This is a so-called upsell offer. Airlines try to capitalize on the customers' willingness to pay of the customers. Both parties benefit: the airline can increase its revenue, meanwhile the customers may receive more personal offers. The difficulty of determining the optimal prices of the upsell offers consists in not knowing the exact willingness to pay which the customers might have. Nevertheless, the airline possesses more information about the customers who have bought a ticket. This information can be used to calculate conditional purchase probabilities which are used in the price optimization problem. More precisely, we investigate whether saving offer sets and products bought by customers during the booking horizon increases the airline's revenue when offering upsells afterwards. Therefor, we assume a multinomial logit model for discrete customer choice behavior among the booking and upsell horizon. Furthermore, capacity is controlled by a choice-based deterministic linear problem (CDLP) in the booking horizon. We solve the upsell price optimization problem and evaluate its solution analytically.

3 - Capacitated price bundling - an analysis of factors influencing the profitability of different strategies
Jacqueline Wand, Ralf Gössinger

For price bundling we assume limited vendor capacity and stochastic willingness to pay (wtp) of several customer segments. In this context, it is questionable whether the advantages of the strategies "no bundling", "pure bundling" and "mixed bundling" observed for the uncapacitated case are still valid. Given the above assumptions, the profitability of strategies is influenced by factors originating from the spheres of capacity and market. The available capacity can possess different levels of product flexibility. To analyze its impact, a distinction is made between dedicated and common capacity, which can be used to produce one or all product types, respectively. Since market segmentation is ambiguous, different numbers of segments, segment sizes, wtps, heterogeneities, etc. can also have an impact on profit. As a starting point, we propose an optimization approach that considers both capacity and market segmentation aspects in a stochastic NLP model. To conduct a full-factorial numerical study, the model is solved for more than 2,000 problem instances. Economic insights are gained by statistically analyzing the impact of characteristics of both, customer segments and capacity on profit. Building on this, profit polynomials of the strategies are fitted and comparatively analyzed in order to delimit their areas of dominance.

4 - Bid-Price Based Order Acceptance for Make-to-Order Production
Nina Lohnert, Kathrin Fischer

Many companies apply the make-to-order (MTO) principle where production only starts after an order has been accepted in order to fulfill individual customer requests. Due to capacity restrictions, however, not every order can be fulfilled and hence, decisions regarding order acceptance have to be made. The objectives to be pursued by a manufacturing company are usually two-fold: On the one hand, companies will strive for (short-term) profit maximization. On the other hand, the goal of providing good service in particular to valuable, returning customers is crucial with respect to long-term business success. These objectives are usually in conflict since valuable customers often get price discounts to tie them more closely to the company. In this talk, a bid price based revenue management strategy for order acceptance and the subsequent scheduling is presented. Two mixed-integer linear programming models are combined in order to determine the orders which are to be accepted and the optimal production schedule. Furthermore, the service aspect is taken into account by defining different aspired service levels for different customer groups. Various settings of customer group specific model parameters are tested on realistic data sets and their results are compared to the performance of the well-known first-come-first-served policy. It can be shown that the approach is successful and works particularly well when the parameter choice is linked to the aspired service levels.

■ WD-47

Wednesday, 14:30-16:00 - Virtual Room 47

MINLP Software and Algorithms

Stream: Mixed-Integer Nonlinear Optimization
Invited session
Chair: *Jan Kronqvist*
Chair: *Ruth Misener*

1 - Nonconvex Quadratic Cuts for Global Optimization of Mixed Integer Quadratic Programs
Arvind Raghunathan, Carlos Jose Nohra Khouri, Nikolaos Sahinidis

Nonconvex quadratic programs (QPs) and mixed-integer quadratic programs (MIQPs) arise in a wide variety of scientific and engineering applications. Given their practical importance, these classes of problems have been studied extensively in the literature and are known to be very challenging to solve to global optimality.

In this talk, we introduce a new family of quadratically constrained programming (QCP) relaxations which are derived via nonconvex quadratic cuts. However, the nonconvex cuts in conjunction with equality constraints yield convex QCP relaxations for the MIQP. In order to construct these quadratic cuts, we solve a separation problem involving a linear matrix inequality with a special structure that allows the use of specialized solution algorithms. We investigate the theoretical properties of the proposed relaxations and show that they are an outer-approximation of a semi-infinite convex program which under certain conditions is equivalent to a particular semidefinite program. We implement the new quadratic relaxations in the global optimization solver in BARON. We test our implementation by conducting an extensive computational study on a large collection of problems. Numerical results show that the new quadratic relaxations lead to a significant improvement in the performance of BARON, resulting in a new version of this solver which outperforms other state-of-the-solvers such as CPLEX and GUROBI for many of our test problems.

2 - The Octeract Reformulator API for the automatic reformulation of optimisation problems
Nikos Kazazakis

We present the Octeract Reformulator, a tool that automates the symbolic reformulation of generic optimisation problems. The Reformulator allows users to abstract reformulation logic into its programming language and save that logic to reuse on other optimisation problems.

The Reformulator allows users to define matching rules, filters, and actions.

Matching rules utilise Octeract Abstract Symbolic Matching to encode symbolic matching logic, e.g., "find all expressions where a logarithm is divided by a bilinear term".

Filters encode the refinement of those matches based on context-sensitive information, e.g., "return only the matches where the expression inside the logarithm is convex and can be negative".

Actions define how to manipulate the filtered expressions and produce a new optimisation problem, e.g., "substitute all expressions inside the logarithms with an auxiliary variable, add a constraint to define that auxiliary variable, and add constraints to enforce that the new variables are always positive".

The Reformulator is available for free as part of the Octeract Engine package, where we have exposed it as a Python library. The combination of the Reformulator and Python results in unparalleled flexibility, as reformulations can be reused or shared with other people.

We describe the motivation behind the design of the Reformulator, and demonstrate how it can be used to automate tasks that would normally take weeks of manual work.

3 - Mixed-integer programming with disjunctions: Designing a solver from the ground up
Joey Huchette

Disjunctive programming (DP) is a powerful framework for modeling complex logic in optimization problems. Typically, DP problems are reformulated as mixed-integer programming (MIP) problems, and then passed to a MIP solver. Crucially, the MIP solver only receives this "flattened" MIP reformulation, and not the original, rich DP structure.

This work explores how an LP-based branch-and-cut solver can take advantage of this DP structure. To that end, we develop a prototype solver for mixed-integer programming that treats disjunctive constraints as first-class objects. We discuss how this DP structure can be exploited within the search tree for dynamic reformulation and domain propagation. We also discuss how this can be done without breaking incremental LP solves, a crucial ingredient for the success of modern branch-and-cut solvers. We present an open-source implementation of our approach, along with results on scheduling problems to illustrate its potential.

The work presented in this talk is joint with Ross Anderson, Bochuan Lyu, and Tu Nguyen.

4 - Intermediate P-split Relaxations between big-M and Convex Hull Formulations
Jan Kronqvist, Ruth Misener, Calvin Tsay

Disjunctions are often encoded by extended convex hull or big-M formulations. While the former provides the tightest relaxation of a single disjunction, the latter results in smaller optimization problem that can be computationally favourable.

We present a new class of formulations in between the convex hull and big-M formulations for disjunctions, resulting in relaxations stronger than the big-M and computationally cheaper than the convex hull. The proposed "P-split" formulations split convex additively separable constraints into P partitions and form the convex hull of the partitioned disjuncts. The parameter P represents the trade-off of model size vs. relaxation strength. Under certain assumptions, the relaxations form a hierarchy starting from a big-M equivalent and converging to the convex hull.

■ WD-49

Wednesday, 14:30-16:00 - Virtual Room 49

Applications of Queues

Stream: Performance Evaluation of Queues
Invited session
Chair: *Faruk Akın*

1 - Admission and Discharge Control in Intensive Care Units
Faruk Akın, E. Lerzan Ormeci

Intensive Care Units (ICUs) are scarce resources and operate most of the time under high occupancy rates. When faced with limited bed availability, arriving patients are sometimes rejected or admitted by discharging an existing patient early, which may result in both increased readmission rates and patient/hospital related costs. To aid in developing implementable admission and discharge policies, we first consider a conceptual ICU setting that serves multiple types of patients, which reflects the trade-offs between first-time and recurring patients, between different health stages as well as between the early-discharge and rejection decisions. We define a so-called readmission orbit whose population consists of patients who are to be readmitted after a previous ICU discharge. We develop a discrete-time Markov Decision Process (MDP) and analyze the model when the ICU has one bed and at most one patient can be in the readmission orbit. We also develop a deterministic fluid model to control admissions and discharges in such an environment. We show that the optimal control of the fluid model in the steady state can be obtained by solving a nonlinear problem. We propose heuristic policies based on these models and evaluate their performances by using a discrete-event simulation platform. Numerical results show that following a policy that combines rejections and early-discharges significantly outperforms both aggressive reject and early-discharge motivated policies.

2 - Large Fork-join Networks With Nearly Deterministic Arrival And Service Times
Maria Vlasiou

We study an N server fork-join queuing network with nearly deterministic arrival and service times. We approximate the length of the largest of the N queues in the network, which has interesting applications such as modelling the delays in large supply chains. We present a fluid limit and a steady-state result for the maximum queue length. This fluid limit depends on the initial number of tasks. Due to their scaling, these results have remarkable differences. The steady-state result depends on two model parameters, while the fluid limit only depends on one model parameter. We extend these results to limits under the same scaling and compare all results numerically. The proofs are based on extreme value theory and diffusion approximations.

3 - An (s, S) Inventory System with Unreliable Service and Repeated Calls in a Random Environment
James Cordeiro, Ying-Ju Chen, Andres Larrain-Hubach

Queueing systems are often used as the foundation for industrial models of all types, to include production lines and inventory systems. In this presentation, we discuss a classical (s, S) inventory model modeled as an M/M/1 retrial queueing system. The inventory system features a single product that experiences Markovian demand and service intervals with random service interruptions. Lead time for replenishment is instantaneous. The Markov-modulated duration of service and inter-demand times permit time-dependent variation of the exponential parameters of these processes, which thus imparts a greater degree of realism to the model. Due to the resulting complexity of the underlying Markov chain, a traffic intensity condition is difficult to obtain via conventional means. We thus employ a novel technique that utilizes a matrix-analytic drift approach to obtain a closed-form drift condition for the stability of the process. Estimates of the steady-state distribution of such models are then used to compute various system performance measures.

4 - Multiserver Real Time System with Limited Maintenance Facilities and Nonpreemptive Priorities
Joseph Kreimer

We consider a real time multiserver system with several servers (such as machine controllers, unmanned aerial vehicles etc.) which can be maintained for different kinds of activities (e.g. active or passive). These systems provide a service for real time jobs arriving via several channels (such as assembly lines, surveillance areas, etc.) . We focus on real time systems (RTS) with a zero deadline for the beginning of job processing. Queueing of jobs in such systems is impossible, since jobs are executed immediately upon arrival, conditional on system availability. That part of the job which is not executed immediately is lost forever and cannot be completed later. The system works under a maximum load of nonstop data arrival. Each server can serve different channels, but not simultaneously. There is exactly one job in each channel at any moment -there are no additional job arrivals to busy channels. It is assumed that the number of maintenance facilities in the system is less than the number of servers. A fixed server may be of one of several kinds (e.g. of activity or quality) with given probabilities. These probabilities can be used sometimes as control parameters. We focus on the worst case analysis of the system with nonpreemptive priorities and limited maintenance facilities. We provide equilibrium equations for steady state probabilities and various performance measures, when both operation and maintenance times are exponentially distributed.

■ WD-55

Wednesday, 14:30-16:00 - Virtual Room 55

Integrating machine learning in optimization methods II

Stream: EURO Working Group Data Science meets Optimisation
Invited session
Chair: *Kevin Tierney*

1 - An Actor-Critic algorithm with Deep Double Recurrent agent to solve Job Shop Scheduling
Marta Monaci, Giorgio Grani

There is a growing interest in integrating Machine Learning techniques and optimization to solve challenging optimization problems. In this work, we propose a Deep Reinforcement Learning methodology for the Job Shop Scheduling Problem (JSSP). The aim is to build up a greedy-like heuristic able to learn on some distribution of JSSP instances, different in the number of jobs and machines. The need for fast scheduling methods is well known, and it arises in many areas, from transportation to healthcare. We exploit the efficacy of Actor-Critic techniques, where the action taken by the agent is influenced by policy considerations on the value function. The procedures are adapted to take into account the challenging nature of JSSP since the state and the action space change not only for every instance but also after each move. For this reason, the agent estimation function is a Deep Neural Network composed of two incident LSTM models and followed by a series of fully connected layers. Preliminary tests show that the model reaches good solutions in a short time, finally proving that is possible to generate new greedy heuristics just from learning-based methodologies. Benchmarks have been generated in comparison with commercial solvers. As expected, the model is able to generalize, to some extent, to larger problems or to instances originated by a different distribution of the processing times.

2 - Benchmarking Surrogate-based Optimization Algorithms on Expensive Black-box Functions
Laurens Bliek, Arthur Guijt, Rickard Karlsson, Sicco Verwer, Mathijs de Weerdt

Surrogate-based algorithms such as Bayesian optimization are especially designed for black-box optimization problems with expensive objectives, such as hyperparameter tuning or simulation-based optimization. In the literature, these algorithms are usually evaluated with synthetic benchmarks which are well established but have no expensive objective, and only on one or two real-life applications which vary wildly between papers. There is a clear lack of standardization when it comes to benchmarking surrogate algorithms on real-life, expensive, black-box objective functions.

In this work, we provide an extensive comparison of seven different surrogate-based algorithms on four expensive optimization problems from different real-life applications. We report the relation between the time spent on learning and optimizing the surrogate model, the accuracy of the surrogate model, and the algorithm performance for all seven algorithms. This provides a better understanding of the different surrogate models and indicates directions for improvements.

Our second contribution is that we make the algorithms and benchmark problem instances publicly available, contributing to more uniform analysis of surrogate-based algorithms. Most importantly, we include the performance of the seven algorithms on all evaluated configurations and problem instances. This results in a unique new dataset that lowers the bar for researching new methods as the number of expensive evaluations is reduced.

3 - Learning a Latent Search Space for Routing Problems using Variational Autoencoders
Kevin Tierney, André Hottung, Bhanu Bhandari

Methods for automatically learning to solve routing problems are rapidly improving in performance. While most of these methods excel at generating solutions quickly, they are unable to effectively utilize longer run times because they lack a sophisticated search component. We present a learning-based optimization approach that allows a guided search in the distribution of high-quality solutions for a problem instance. More precisely, our method uses a conditional variational autoencoder that learns to map points in a continuous (latent) search space to high-quality, instance-specific routing problem solutions. The learned space can then be searched by any unconstrained continuous optimization method. We show that even using a standard differential evolution search strategy our approach is able to outperform existing purely machine learning based approaches.

Wednesday, 16:30-17:30

■ WE-01

Wednesday, 16:30-17:30 - Bulding A, Amphitheatre

Perspectives on the Role of Analysis in High-level Political Decisions

Stream: Plenaries
Plenary session
Chair: *Rudolf Vetschera*

Wednesday, 17:30-19:00

■ WF-01

Wednesday, 17:30-19:00 - Bulding A, Amphitheatre

Closing Session

Stream: Opening and Closing
Plenary session
Chair: *Rudolf Vetschera*
Chair: *Nikolaos Matsatsinis*

1 - Closing Session
Nikolaos Matsatsinis, Rudolf Vetschera

Closing Session

Streams

Actuarial modeling and risk management

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Track(s): 5 29

AI & Innovation in Sustainable Finance

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Track(s): 1 37

AI and Decision Making

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Track(s): 7 29

Analytics in Service Management

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Track(s): 27

Automated Warehouse System

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Behavioral Decision Making

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Track(s): 21

Behavioral Modelling

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Behavioral Operations Management

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Big Data and Optimization

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Bilevel Optimization

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Business Analytics

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Track(s): 33

Combinatorial Optimization

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Track(s): 3 6 27 34 35 56

Conic Optimization and Related Topics

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Track(s): 22

Continuous optimization (contributed)

Track(s): 3 24 50

Corporate strategies

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Track(s): 36

Cutting and Packing

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Track(s): 7 37 60

Data Envelopment Analysis and Performance Measurement

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Data Mining and Statistics

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Track(s): 28

Data Science and Analytics (contributed)

Track(s): 3 27 28 54

Decision Analysis and Decision Analytics

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Track(s): 26

Demand and Supply in Consumer Goods and Retail

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Track(s): 8 45

Derivative-free Optimization

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Track(s): 23

Descriptive and prescriptive behavioural OR studies

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Track(s): 21

Disaster and Crisis Management

Track(s): 30

Dss

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Track(s): 29 31

Dynamical Models in Sustainable Development

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Track(s): 36

Dynamical Systems and Mathematical Modeling in OR

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Track(s): 2 38

Dynamics and Games

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Track(s): 1 29

Economics and game theory (contributed)

Track(s): 2 40

Emerging Applications in Portfolio Selection and Management Science

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Track(s): 4 47

Emerging Collaborative Economics and Management under Uncertainty

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Track(s): 4 47 50

Emerging Research on Education, Competences and Labor Markets

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Track(s): 39

Emerging technical and financial aspects of energy problems

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Engineering Optimization

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Engineering Optimization II

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Track(s): 44

Enterprise risk management

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Track(s): 1 42

Environmental Sustainability in Supply Chains

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Track(s): 43

Epidemiological modeling and decision support

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Track(s): 43

Ethics in Analytics

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Track(s): 26

Ethics in OR

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EURO Doctoral Dissertation Award

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Track(s): 52

EURO Excellence in Practice Award

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Track(s): 36

EURO Working Group Data Science meets Optimisation

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Track(s): 55

Game Theory and Operations Management

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Track(s): 25 31 39

Game Theory, Solutions and Structures

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Track(s): 2 35 36

Global Optimization

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Track(s): 24

Governance Analytics

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Track(s): 40

Group Decision Making

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Track(s): 25

Heuristic Optimization

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Track(s): 6 33 57

Humanitarian Operations

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Track(s): 4 38

Information Systems and Software for OR

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Track(s): 30

Intelligent Decision Methods

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Track(s): 29

Keynotes

Track(s): 1 48 62

Last minute changes

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Track(s): 56 63

Lot Sizing, Lot Scheduling and Production Planning

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Track(s): 3 48

Mathematical Models in Macro- and Microeconomics

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Track(s): 1 41

Mathematical Optimization and Data Science

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Track(s): 3 28

Memorial Session - in honour of Jaap Spronk

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Track(s): 50

Mixed Integer Linear Programming

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Track(s): 6 30

Mixed-Integer Nonlinear Optimization

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Track(s): 42 47

Modelling and Simulation of Social-Behavioural Phenomena in Creative Societies

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Track(s): 42

Multiobjective Combinatorial Optimization

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Multiobjective Optimization

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Multiple Criteria Decision Analysis

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Network Optimization

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Track(s): 31

New challenges for financial modelling

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Track(s): 5 33

Non linear optimization in finance

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Nonlinear Optimization

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Opening and Closing

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Operational research in financial and management accounting

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Operations/Marketing Interface

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Optimal Control Theory and Applications

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OR and the Arts, Creativity

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OR Education Initiatives

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OR for Development, Developing Countries and Sustainable Development

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OR for intelligent Energy Services

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OR in Aviation

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Track(s): 5 51

OR in Climate Policy and Planning

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Track(s): 52

OR in Computational Biology, Bioinformatics and Medicine

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OR in Marketing

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OR in Military, Defense, and International Security

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OR in Quality Management

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OR in Sports

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Track(s): 43

OR Journals

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Track(s): 37

OR Meets Computation

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Track(s): 3 41

ORAHS: OR in Health and Healthcare

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Organizational and Information Management

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Track(s): 4 52

Performance Evaluation of Queues

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Track(s): 2 49

Plenaries

Track(s): 1 21

Practice of OR (Making an Impact)

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Track(s): 44

Production and logistics and revenue management (contributed)

Track(s): 3 41 46

Production, Service and Supply Chain Management

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Queues with Strategic Customers

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Revenue Management and Pricing

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Track(s): 46

Risk management in Finance

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Track(s): 2 36

Routing, Logistics, Location and Freight Transportation

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Track(s): 4 7 29 37 39 40

Scheduling and Project Management

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Soft OR and Problem Structuring Methods

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Software for Optimization

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Specific Applications of OR (contributed)

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Track(s): 45

Specific Applications of OR in Agriculture, Forestry and Fisheries

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Specific Applications of Stochastic Modeling and Simulation in Engineering, Management and Science

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Stochastic and Robust Optimization

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Track(s): 5 25

Stochastic Dynamic Programming

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Stochastic Modeling in Health Care

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Stochastic Models in Manufacturing and Services

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Sustainable Supply Chains

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System Dynamics Modeling and Simulation

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The 2nd International Workshop on Artificial Intelligence for RAILwayS (AI4RAILS)

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Timetabling and public transport

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Vector and Set Optimization

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