Technical Program

Monday, 8:30-10:00

■ MA-03

Monday, 8:30-10:00 - 200AB

Opening session

Stream: Plenary sessions
Plenary session

Monday, 10:30-12:00

■ MB-01

Monday, 10:30-12:00 - 307B

Data science meets optimization

Stream: European working group: Data science meets optimization
Invited session
Chair: Patrick De Causmaecker

1 - **Cost-sensitive support vector machines classification**
Emilio Carrizosa, Sandra Benítez-Peña, Rafael Blanquero, Pepa Ramírez-Cobo

In this talk we propose an extension of the traditional Support Vector Machine (SVM) paradigm, by accommodating asymmetric misclassification costs. This allows one to model the case in which false positive and false negative cases may have very different consequences. The key idea is to solve the standard SVM convex quadratic problem, but adding linear constraints imposing upper bounds on the false positive and negative rates on an independent test set. The problem is written as a Mixed Integer NonLinear Problem (MINLP), reduced to a series of convex quadratic MINLPs. Feature Selection will also be addressed.

2 - **Optil.io: Evaluation platform for data science and optimization algorithms**
Szymon Wasik, Maciej Antczak, Jan Badura, Artur Laskowski, Tomasz Sternal

In general, evaluation of any algorithmic solution always requires specialized data processing mechanisms integrated with a methodology that allows to compare it objectively with other solutions. Online platforms designed with Evaluation-as-a-Service (EaaS) model in mind significantly support such an assessment. This model, in brief, was defined as a paradigm of keeping the evaluation data in the cloud and allowing the users to access them via dedicated interfaces. One of the best-known platforms that impact the data science research significantly is Kaggle, which is devoted to the evaluation of data mining algorithms. Here, we present an Optil.io platform, a more general alternative to Kaggle, which objective is to reliably evaluate algorithmic solutions in a safe cloud-based environment proposed for scientific and industry-inspired complex optimization problems. It supports online judge architecture with the following flow: a participant submits the source code of its solution, which is next compiled and assessed based on the standard set of test instances not available to the user directly. After submission, the author can continuously observe how his solution rank is changing in comparison with other submitted algorithms. We believe that this system can become a major evaluation platform for Data Science and Optimization Algorithms.

3 - **Design of heuristic algorithms as an optimization problem**
Patrick De Causmaecker

The design of heuristic algorithms received ample attention over the last decades. The project on metaheuristics, started in the 80's of the previous century, conceptualised the design of heuristics that developed after the Second World War. Its concepts centred on search diversification and intensification. These could be applied to a many combinatorial optimisation problems in theory and practice. Several conceptual frameworks were defined allowing fast development of powerful heuristics by merely specifying domain dependent components. Local search and population based as well as evolutionary are just a few labels to distinguish between different kinds of metaheuristics as they were developed, often building on older ideas. In the first decade of the 21st century, the idea of hyperheuristics was taken forward. It was aimed at separating domain expertise based abilities to suggest clever and efficient tricks in specific situations from expertise and ability in optimisation and heuristics. Important realisations in automated algorithm construction, tuning and selection emerged. We show by example that a heuristic engineering discipline has emerged which today allows experienced algorithm designers to quickly come up with powerful solutions for very complex real world problems. Casting the design problem into an optimisation problem helps automation. Significant advantages have been demonstrated. We state some open questions and argue in favour of a theoretical foundation.

4 - Optimization in large graphs
Pieter Leyman, Patrick De Causmaecker

In the context of large graphs with tens of thousands or more nodes, a great deal of research has been conducted on finding communities, or groups of individuals connected to a predefined degree. Two prime examples are the analysis of a network of users such as Facebook, or the mapping of neural pathways in the human brain. Especially in the past couple of years there has been a genuine flood of publications discussing all manner of (meta)heuristic approaches to solve different clustering problems in large graphs. A strong conceptual and theoretical foundation of connectedness in large graphs is, however, required. Such a conceptual model should allow for determining specific characteristics (e.g. the number of connections between a subset of the network) that one is looking for in graphs. In doing so, a purely black-or-white view on graph characteristics can be avoided. Additionally, shortcomings of commonly used functions such as modularity density can be overcome. We discuss the pitfalls inherent to the current definitions of connectedness and propose a first step towards a conceptual model for optimization in large graphs.

■ MB-02

Monday, 10:30-12:00 - 308B

Operational research in financial and management accounting

Stream: Operational research in financial and management accounting
Invited session
Chair: Matthias Amen

1 - Survey on tax management accounting in German SME as a basis for supporting operative planning
Markus Puetz

Due to the relevance of tax effects for value-based management in general, this presentation addresses an initial survey on tax management accounting in German small and medium-sized enterprises (SME). This survey serves as a basis for supporting the use and further development of operative planning taking into account tax effects. The online questionnaire of the survey is introduced at first. Subsequently, the results of the survey study are sketched out. In addition to frequency tables, the use of contingency tables is described. Ensuing from a company size specific variable, its interrelation to other single variables and, for reasons of significance, a combination with a layer variable is explained. Finally, implications for supporting operative planning approaches that take into account tax effects are depicted.

2 - Further development of an operative planning approach with several production sites and different trade tax collection rates
Matthias Amen

For on an existing basic approach for operative planning with several production sites and different trade tax collection rates this presentation addresses aspects of its further development. The aforementioned approach that has been specified for an effective handling of different tax collection rates on municipality level concerning to various German production sites inside short-term program planning tasks is introduced at first. Subsequently, as a first aspect of further development, a possibility for the classification of different constellations of company-specific production sites is presented. The basic operative planning approach includes a nonlinear objective function and the related optimization problem is solved by using an algorithm with an implementation of the generalized reduced gradient method. Finally, as a second aspect of further development, possible improvements of solving the nonlinear optimization problem concerned are depicted.

3 - A continuous auditing framework for human-machine-collaboration in the audit function
Alexander Rudyk

Human-machine-collaboration will be more effective than purely human or purely algorithmic decisions. Such collaboration can be built on decision aids that combine computer-driven data analysis with human intuition and reasoning in a feedback cycle where machine analysis supports human decisions which are in turn used to train machine learning algorithms. We test this hypothesis by developing a framework for internal and external auditors to process data received from Continuous Auditing (CA) systems, capture auditor decisions and use the resulting data to train decision-aiding classifiers. This aims to transform existing, mostly static audit analytics into a dynamic, self-learning system. We hypothesize that the right interface design can help humans trust in algorithmic decision-making. Current audit analytics are mostly driven by explicit rules based on auditors' hypotheses of potential red flags. Data sets are often unbalanced as there are far less abnormal than normal transactions, which leads to "alarm floods" where the large number of false positives makes manual filtering infeasible. Providing a framework that uses classification to pre-filter rules-based data will help to make continuous auditing more applicable and efficient. We present the theory of the framework and an implementation built on Microsoft SharePoint, which will be tested in a real-world usage context.

4 - Modeling probabilty of default term structures: A new approach using scoring recalibration
Daniel Börstler, Sascha H. Moells

The experiences resulting from the recent global capital market crisis show that a deliberate estimation and management of credit risks is of crucial importance for banks and the economic welfare. Reacting to these distortions and in order to capture future risks more adequately international standard setters have established new general risk-related regulatory requirements (e.g. EBA/CP/2016/10) as well as new standards for financial risk reporting (e.g. IFRS 9) changing the formerly applied one-year risk horizon towards a "lifetime" perspective of the financial instrument. Against this background, the paper analyzes common approaches for the timely adjustment of probability of default(PD) term structure-models using a set of quantitative and qualitative criteria. Furthermore, we develop an entirely new approach for PD term structures modelling. This "score calibration approach" is - although building on the commonly known credit scorecard models - a general approach outranking current approaches regarding complexity as well as accuracy of the estimation results. The developed approach offers a complete framework allowing tailor-made solutions not only for portfolios with a long data history but also for portfolios with incomplete availability of data. Thus, the method is particularly suitable for the derivation of target values within large banking groups typically requiring values for the core portfolio and for marginal portfolios (e.g. foreign subsidiaries).

■ MB-03

Monday, 10:30-12:00 - 200AB

Keynote speaker: Dave Stanford

Stream: Keynote sessions
Keynote session
Chair: Steve Drekic

1 - Key performance indicators and their optimal performance
David Stanford

Key Performance Indicators (KPIs) have been a popular tool for sorting out the question of urgency in health care systems, by setting the standards for time to initiation of treatment for these various populations. KPI standards typically comprise a time limit for treatment to begin and a compliance probability stating the minimum acceptable fraction of the patient class that adheres to it. KPI standards represent a system of constraints, and lack a goal to be optimized. This tutorial commences with a review of several diverse areas in healthcare where KPI standards arise. We next present an appropriate set of objective functions for optimal performance of a KPI system, which relate to minimizing the amount of excess waiting that occurs. We then show that the Accumulating Priority Queueing (APQ) discipline is well-suited to facilitate compliance of diverse patient populations served by a common facility. The remainder of the presentation addresses what we have learned about the various objectives, their relationship to each other, and their optimal performance. We are particularly interested in the performance of a simple Rule of Thumb which assigns priority to customers in each KPI class in inverse proportion to that class's waiting time limit.

■ MB-05

Monday, 10:30-12:00 - 203

Ensemble learning for business analytics

Stream: Multiple classifier systems and applications
Invited session
Chair: Sureyya Ozogur-Akyuz

1 - Time series forecasting using bootstrap-based ensemble
Donghwan Kim, Jun-Geol Baek

Recently, interest in a series of observations collected over time, such as exchange rate, temperature, market price, and process variables, is increasing, and this data is called time series data. The most commonly used time series analysis model is the ARIMA methodology. ARIMA uses a linear combination of past patterns and white noise, which is a random variable, to predict the future value of time series. This is advantageous in that its form is simple and relatively predictive. At this time, studies were made to combine multiple models into a single model, which is the ensemble method. In general, the ensemble method is known to have better performance than a single model. Then, the prediction results of each model can be integrated using various methods such as mean, median, mode, and weighted voting. This study proposed a time series prediction method based on data ensembles rather than model as a bootstrap-based ensemble technique. In this paper, we propose a method to improve the performance of predictive models with simple structure and apply them to non-linear time series data. Through the preliminary study, we compare the feasibility of the proposed algorithm and the performance of the existing methodology. In most cases, we confirmed that the algorithm has similar or better performance than the existing algorithm. Especially when there is no seasonality and the trend is clear.

2 - Evaluating the short term effect of cross market discounts in purchases using neural networks
Vera Miguéis, Ana Camanho, João Cunha

Promotional discounts have gained relevance in some companies marketing mix to appeal to price-sensitive customers. Cross-market discounts are an increasingly used strategy that consists of offering linked discounts in unrelated markets that have the same target customers but are not in direct competition with each other. This study aims to assess whether the implementation of a cross market discount campaign by a retailing company encouraged customers to increase their purchases level. It contributes to the literature by using neural networks to detect novelties in a real context involving cross market discounts. Besides the computation of point predictions the methodology proposed involves the estimation of neural networks prediction intervals. Sales predictions are compared with the observed values in order to detect significant changes in customers' spending. The use of neural networks is validated through the comparison with support vector regression forecasting estimates. Despite the increased popularity of cross market discounts in recent years, the results obtained in this study showed that in the first months after the launch of a promotional campaign by the retailer, the purchasing behavior of the customers who utilized the voucher did not change significantly. The observed values of sales are inside the neural networks prediction intervals.

3 - Data-driven system analysis and inferential modelling
Jian-Bo Yang, Dong-Ling Xu

In this short paper, we introduce the main concepts of a new data-driven evidential reasoning (ER) framework. It is established to analyse relationships between the output and inputs of a complex system with different types of uncertainty. It consists of three types of models: data model, evidence model and state model. The data model is used to record the system observations or experimental data, which are deemed to reflect the statistical or distributed relationships between the output and inputs of the system. The evidence model is constructed by mapping data to a set of evidence that is each partitioned into evidential elements pointing to system states and together represents system behaviours probabilistically. In the evidence model, dependency for each pair of evidence is measured. The state model is used to characterise different system states and changes. In the joint evidence-state model, the weight of evidence is given as the probability that a state is true given that the evidence points to the state. From system inputs, multiple pieces of evidence with different degrees of dependency and weights can be acquired and combined to inference system output. In this ER framework, different types of uncertainty including randomness, ambiguity and inaccuracy can be modelled in an integrated manner for robust system analysis, modelling and prediction. In this paper, the main concepts and structures of these models and the inference process are discussed and illustrated.

4 - Regularized ensemble pruning by optimizing accuracy diversity trade-off
Sureyya Ozogur-Akyuz

Recent studies show that the decision of the ensemble of clusters gives more accurate results than any single clustering solution. Accuracy and diversity of an ensemble are the important factors which effect the overall success of the algorithm. There is a tradeoff between accuracy and diversity, in other words, you sacrifice one while you increase the performance of the other. On the other hand, the optimum number of clustering solutions is another parameter that effect the final result. Recently finding the best subset of an ensemble by pruning methods has become one of the most challenging problems in the literature. The proposed study here aims to find a best model which optimizes the accuracy and diversity trade-off by selecting the best subset of cluster ensemble. The proposed model optimizes accuracy and diversity simultaneously by regularization of cardinality of subset of ensembles and by an additional bound constraint.

■ MB-06

Monday, 10:30-12:00 - 204A

CORS student paper competition (open)

Stream: CORS student paper competitions
Invited session
Chair: *Mehmet Begen*
Chair: *Nadia Lahrichi*

1 - CORS Student paper competition (Open category)
Mehmet Begen

Presentations of finalists for the CORS student paper competition (open category).

■ MB-07

Monday, 10:30-12:00 - 204B

Expert elicitation

Stream: Expert judgement elicitation
Invited session
Chair: *Robin Rivest*

1 - Adventures in behavioural aggregation
John Paul Gosling

Over recent years, several competing expert group knowledge elicitation protocols have emerged that can be broadly categorised as mathematical aggregation, supra-Bayesian hierarchical modelling and behavioural aggregation. The first two are based upon mathematical models of varying complexity and the latter focuses on gaining a consensus through structured discussion. Each protocol has pros and cons; nevertheless, over the past 15 years, I have been employing mainly behavioural aggregation techniques in many disparate application areas. In this talk, I will briefly describe the Sheffield Elicitation framework (which is a protocol based upon behavioural aggregation) and go into the details of a few group elicitation exercises that I have conducted highlighting the real challenges of aggregating knowledge in this manner and the additional benefits that can be gained.

2 - Predicting antimicrobial resistance
Alec Morton, Abigail Colson, Tim Bedford, Itamar Megiddo, Ramanan Laxminarayan

Antimicrobial resistance (AMR) threatens to set medicine back decades. Antibiotic stewardship programs, improved infection control, and new antibiotic therapies are needed to ensure we retain access to effective treatments against bacterial disease. The value of these programs depends on the future prevalence of AMR, which is highly uncertain. We use two methods to predict the future prevalence of resistance in invasive Escherichia coli and Klebsielle pneumoniae isolates in four European countries and better understand the uncertainty surrounding future resistance rates. First, we use the Classical Model of structured expert judgement to elicit uncertainty assessments from experts and combine those assessments according to the experts' performance as probability assessors. Second, we use linear to predict future resistance rates based on historical data collected by the European Antimicrobial Resistance Surveillance Network. The experts predicted lower future rates of resistance than the model for pathogen-antibiotic combinations that already have established resistance (i.e., E. coli and cephalosporins, K. pneumoniae and cephalosporins, and K. pneumoniae and carbapenems in Italy). For pathogen-antibiotics combinations for which current resistance rates are near zero, the experts predicted higher future rates of resistance than the model. The experts also expressed more uncertainty about future resistance rates than is reflected in the model's confidence intervals.

3 - The refined partition method: Elicitation of dependence from experts with minimally informative distributions
Christoph Werner

Modelling dependence is important for various applications in probabilistic risk assessment and decision making under uncertainty as neglecting dependence in multivariate uncertainties can distort model output severely. However, modelling and quantifying dependence between uncertain variables is challenging, in particular when relevant historical data are not available. In this case, modelling a joint distribution through the use of expert judgement is the only sensible option. Without restrictive parametric assumptions, it is easy to either ask too little or too much information from experts. The first introduces the issue of underspecification, i.e. we do not have enough information for choosing a unique distribution. Eliciting too much information can lead to overspecification, meaning that a high number of assessments can result in infeasible and contradictory assessments rather quickly. In order to address both issues, we present the refined partition method which offers high flexibility with regards to the area of the distribution that we specify, its level of detail and the order in which the experts specify dependence information. It addresses underspecification as unspecified parts are determined by minimum information methods with respect to the independent distribution. Overspecification is resolved through a process which is sequentially consistent, avoiding infeasible outcomes due to proportional assessments.

4 - A numerical experiment on the possibility of getting the ahp solution with much less pairwise comparisons
Robin Rivest

The number of comparisons required to fill the pairwise comparison (PC) matrix used in the quantification of preferences and in particular in the AHP can become tedious as the number of alternatives considered becomes larger (grows with O(N2)). Priority vectors which are obtained from normalizing principal eigenvectors of PC matrices can be computed even if some PC entries are missing under some conditions. This study aims to determine whether or not some PC entries can be systematically omitted in the elicitation process of the AHP without significantly distorting the final solution. It is expected that these omissions will be guided by a number of simple heuristics that will have been verified empirically by way of numerical simulations. The simulations compare priority vectors obtained from complete matrices with those obtained by omitting some PC entries. The measure used to evaluate distances between priority vectors is the angle based on the cosine similarity of vectors.

■ MB-08

Monday, 10:30-12:00 - 205A

Freight demand modeling

Stream: City logistics and freight demand modeling
Invited session
Chair: *Carlos Gonzalez-Calderon*
Chair: *Jose Holguin-Veras*

1 - Generalized Noortman and Van Es' empty trips model
Carlos Gonzalez-Calderon, Jose Holguin-Veras, Johanna Amaya, Ivan Sanchez-Diaz, Ivan Sarmiento

This paper presents a generalized Noortman and Van Es' empty trip model that considers commodity groups and vehicle types. The model allows the modeler to identify the commodities that produce empty trips per se along with the commodities that contribute differently to the generation of empty trips. The method was validated using data collected in Colombia as part of the national Freight Origin-Destination Survey. The results highlight that the not all commodities contribute in the same way and specialized goods impact more in the generation of empty trips. In the same context, it was also found that for the same commodity, the contributions differ across vehicle types. The key contribution of the model is that it produces more precise estimates as it includes the impacts of the cargo type in the generation of empty trips.

2 - Freight demand synthesis including modal split-a combined estimation procedure
Lokesh Kalahasthi, Jose Holguin-Veras

Freight Demand Synthesis (FDS) is the process of estimating freight demand from the available data such as traffic counts, cost matrix, productions, and attractions; bypassing the need for an extensive data collection efforts. Although a limited amount of research has been conducted using different model forms and estimation procedures, the bulk of this work has focused on FDS either for all modes or truck alone; no research has been conducted considering mode choice. This research is an initial attempt towards overcoming this gap. This research develops a combined model for FDS that incorporates the estimation of modal split between rail and truck. A gravity model is adopted for the estimation of trip distribution; a binary logit model for modal split between rail and truck; and Noortman and van E's model is used for empty trips. It is assumed that the total productions and attractions, the network data, and the link flows by both modes are available. The results show that the quality of the estimates depend upon the number of link flows available. Application on a sample network shows that, the model provides reasonably good estimates for O-D table and modal split. This research serves as a potential tool for transportation planners in evaluating various policy outcomes.

3 - Coordination in delivery points networks for e-commerce last-mile
Ivan Sanchez-Diaz, Ivan IvanC, Wouter Dewulf

E-commerce growth poses a number of challenges to urban logistics. Research on e-commerce home deliveries has mainly addressed the impacts of delivery points (DP) (i.e. pickup points, drop-of points, lockers) in terms of the total number of vehicle kilometres travelled (VKT) and reduction of failed deliveries. It is common to see studies that consider DP as an occasional solution. However, the growth of e-commerce and the challenges this growth entails have led logistics providers to build denser networks of DP and integrate the location of these points into their planning process. Therefore, considering DP as an extra tier of the supply chain may be a more realistic approach. Moreover, the decision of location and catchment area of a DP has implications on the net VKT and it is not exclusively interesting for logistics providers but also to other stakeholders such as receivers and society represented by a public sector. This paper aims to provide a framework to model the decision process of establishing a network of DP by considering the implications of this decision for the different stakeholders involved in last mile of urban distribution. Since the implications of this decision are not unilateral the frameworks aim to consider the costs and benefits for multiple stakeholders rather than just one. Data from a case in Brussels illustrates the trade-offs among the stakeholders with regard of the decision of the number of DP in a network.

■ MB-09

Monday, 10:30-12:00 - 205B

2017 David Martell student paper prize in forestry

Stream: CORS SIG on forestry
Invited session
Chair: *Jean-Francois Audy*
Chair: *Claudia Cambero*
Chair: *Taraneh Sowlati*
Chair: *David Martell*

1 - Evaluating order acceptance policies for divergent production systems with co-production
Ludwig Dumetz

The impacts of using different order acceptance policies in manufacturing sectors are usually well known and documented in the literature. However, for industries facing divergent processes with co-production (i.e. several products produced at the same time from a common raw material), the evaluation, comparison, and selection of policies are not trivial tasks. This paper proposes a framework to enable this evaluation. Using a simulation model that integrates a custom-built ERP, we compare and evaluate different order acceptance policies in various market conditions. Experiments are carried out using a case from the forest products industry. Results illustrate how and when different market conditions related to divergent/co-production industries may call for Available-To-Promise (ATP), Capable-To-Promise (CTP), and other known strategies. Especially, we show that advanced order acceptance policies like CTP may generate a better income for certain types of market and, conversely to typical manufacturing industries, ATP performs better than other strategies for a specific demand patterns.

2 - Agent-based simulation of multiple-round timber combinatorial auction
Farnoush Farnia

This paper presents a simulation-based analysis of a multiple-round timber combinatorial auction in the timber industry. Currently, most timber auctions are single-unit auctions (i.e., each forest stand is sold separately). However, other types of auctions could be applied to take advantage of the various needs of the bidders with respect to species, volumes, and quality. This study aims to analyze the use of combinatorial auction to this specific context using a simulation approach. Various number of auctions per year, periodicity, lot size, and number of bidders are considered as parameters to set up the different market configurations. The outcomes of both combinatorial auction and single-unit auction are compared with respect to different setup configurations. This analysis shows that combinatorial auction can bring more profit for both seller and buyer when the market is less competitive.

3 - A bilevel model formulation for the distributed wood supply planning problem
Gregory Paradis

The classic wood supply optimisation model maximises even-flow harvest levels, and implicitly assumes infinite fibre demand. In many jurisdictions, this modelling assumption is a poor fit for actual fibre consumption, which is typically a subset of total fibre allocation. Failure of the model to anticipate this bias in industrial wood fibre consumption has been linked to increased risk of wood supply failure. In particular, we examine the distributed wood supply planning problem where the roles of forest owner and fibre consumer are played by independent agents. We use game theory to frame interactions between public forest land managers and industrial fibre consumers. We show that the distributed wood supply planning problem can be modelled more accurately using a bilevel formulation, and present an extension of the classic wood supply optimisation model which explicitly anticipates industrial fibre consumption behaviour. We present a solution methodology that can solve a convex special case of the problem to global optimality, and compare output and solution times of classic and bilevel model formulations using a computational experiment on a realistic dataset. Experimental results show that the bilevel formulation can mitigate risk of wood supply failure.

■ MB-10

Monday, 10:30-12:00 - 205C

Nonsmooth optimization algorithms

Stream: Algorithmic nonsmooth optimization and differen-

tial equation solving
Invited session
Chair: Andrea Walther

1 - Clustering in large data sets with the limited memory bundle method
Napsu Karmitsa, Adil Bagirov, Sona Taheri

Clustering is among most important tasks in data mining. This problem in large data sets is challenging for most existing clustering algorithms. Here we introduce a new algorithm based on nonsmooth optimization techniques for solving the minimum sum-of-squares clustering problems in large data sets. The clustering problem is first formulated as a nonsmooth optimization problem. Then the limited memory bundle method [Haarala et.al. Math. Prog., Vol. 109, No. 1, pp. 181-205, 2007] is modified and combined with an incremental approach to solve this problem. The algorithm is evaluated using real world data sets with both large numbers of attributes and large numbers of data points. The new algorithm is also compared with some other optimization based clustering algorithms. The numerical results demonstrate that the new algorithm was both efficient and accurate and it can be used to provide real-time clustering in large data sets.

2 - On optimality conditons for piecewise smooth functions
Andreas Griewank

Functions defined by evaluation programs involving smooth elementals and absolute values as well as the max- and min-operator are piecewise smooth. Using piecewise linearization we derived in an earlier work for this class of nonsmooth functions first and second order conditions for local optimality, which are necessary and sufficient, respectively. These generalizations of the classical KKT and SSC theory assumed that the given representation of the objective satisfies the Linear-Independence-Kink-Qualification (LIKQ). In this paper we relax LIKQ to the Mangasarin-Fromovitz-Kink-Qualification and discuss the computational complexity of the corresponding numerical test. We conjecture that the verification of MFKQ and related issues is NP hard.

3 - On convexity conditions for piecewise smooth objective functions
Andrea Walther, Andreas Griewank

Functions defined by evaluation programs involving smooth elementals and absolute values as well as the max- and min-operator are piecewise smooth. Using piecewise linearization we derived in an earlier work for this class of nonsmooth functions first and second order conditions for local optimality, which are necessary and sufficient, respectively. These generalizations of the classical KKT and SSC theory assumed that the given representation of the objective satisfies the Linear-Independence-Kink-Qualification (LIKQ). In this paper we relax LIKQ to the Mangasarin-Fromovitz-Kink-Qualification and develop constructive conditions for three local convexity conditions. These are: the existence of a supporting hyperplane at a given point for the function itself, or its local linearization, and the convexity of its local piecewise linearization on a neighborhood. As a consequence we show that first order convexity in the sense of is always required by subdifferential regularity as defined by Rockafellar and Wetts, and is even equivalent to it under MFKQ.

4 - Implementation example of algorithmic differentiation for piecewise smooth functions with the ABS-normal form
Koichi Kubota

We had developed prototype programs of automatic differentiation or algorithmic differentiation for FORTRAN and C++ language which had a lack of systematic and appropriate treatments of non-differentiable points. The ABS-normal form given by A.Griewank, abbreviated by ANF, is one of the best methods to handle such situation. We have developed C++ operator overload type system for algorithmic differentiation and have combined this form in our system. With this system, we have tried to compute some examples of non-smooth and non-convex optimization, and have checked the optimality at a given non-differential point by solving linear programs many times by using linear programming solvers. In this stage, our system construct a computational graph explicitly for traversing the graph many times in order to combine forward and reverse mode algorithmic differentiation for computation of the derivative matrices given by the ANF. We now work on use of the ramp function and the truncated power functions instead of absolute function for computing one of the sub-derivatives, which should be compared to ANF from the implementation point of view.

■ MB-11

Monday, 10:30-12:00 - 206A

Revenue management, pricing, managerial accounting

Stream: Revenue management, pricing, managerial accounting (contributed)
Contributed session
Chair: Álvaro Flores

1 - A Reward determination framework for crowdsourcing
Gülfem Isiklar Alptekin, Asli Sari

Crowdsourcing has started to gain much more attention in software engineering research areas, from coding to development by means of special platforms and applications. It is seen as a good alternative for academia and industry as a means of software development approach. In crowdsourcing, multiple developers compete and independently work to produce solutions to given problems by requesters. Only the submissions that pass a minimum acceptance score are accepted. In general, the submission with the highest score is determined as the winner and the corresponding developer receives the award. Each developer has his own objective to maximize its own utility. Similarly, requesters have the objective to maximize the quality of the solutions in respect to their budget constraints. Thus, an equilibrium model needs to be built between requesters and developers, in order to determine the optimum rewards for each software task. This paper focuses on the crowdsourcing concept and research in software engineering from economical point of view. First, currently popular commercial applications, platforms, business models are given. Then, a non-cooperative game theory is applied as an appropriate methodology for the competitive environment. The players are determined as the requesters. Solving the game, the mutual best response strategies that determine the equilibrium point(s) are studied. Using these optimum rewards, requesters may calculate their expected demands and expected profits.

2 - Markdown optimization for geographically diversified customers using randomized decomposition approach
Andrew Vakhutinsky, Kresimir Mihic

We describe markdown optimization problem arising when an e-commerce retailer has to sell the remaining inventory to maximize its profit. Since the sales orders are to be fulfilled at geographically dispersed location and from different fulfillment centers, they generally involve different delivery costs. In addition, the online customers may have different price elasticity and the retailer can offer a limited number of personalized promotions to the customers. During the sales period the inventory incurs time-proportional holding costs. At the end of the sales period all unsold inventory is liquidated at certain salvage price. The revenue is based on the demand model, which includes such factors as price discount, promotional lift, demand transference, and seasonality effects. We use a regularized regression approach similar to ridge regression to fit the demand model using the merchandising and geographical hierarchy. Due to the essentially nonlinear revenue function and binary decision variables, the optimization problem is solved using randomized decomposition (RD) approach that we present in our talk. Starting from a feasible solution, RD solver partitions the problem decision variables into a randomly ordered list of randomly generated subsets. RD then optimizes over the variables in each subset, keeping all other variables fixed. We describe the results of our computational experiments using the real-life data from a national-level e-commerce retailer.

3 - Cost sharing with consideration of network service quality between internet service provider and content provider
Kwei-Long Huang, Chia-Wei Kuo

As global mobile data keep growing and network congestion occurs more frequently, users are complaining about the low-quality internet service. Internet service provider's reputation is highly determined by users' satisfaction so that the provider may choose to improve service quality by expanding the network bandwidth. On the other hand, content provider who provides services over internet will gain benefit without paying cost for bandwidth expansion, which reduces the willingness of the internet service provider to expand bandwidth. In this study, we consider a cost-sharing contract between the internet service provider and the content provider, in which the latter will share part of cost of infrastructure. In the basic model, the internet service provider first decides its optimal bandwidth, and then the content provider decides the optimal subscription fee charging for users. Last, users decide whether to subscribe content or not. Service quality is considered and measured by the usage of the bandwidth. Several cooperation scenarios are studied, in which internet service provider and content provider are able to make different decisions, such as the scale of bandwidth or the proportion of maintenance cost shared by the content provider. Through the numerical analysis, we show that cost sharing promotes the collaboration between these two parties, and the content provider is better off by sharing the expansion cost.

4 - Trial-offer markets with continuation
Álvaro Flores, Pascal Van Hentenryck, Gerardo Berbeglia

Trial-offer markets, where customers can sample a product before deciding whether to buy it, are ubiquitous in the online experience. These online markets are particularly interesting because of their greater opportunities in shaping the customer experience and their flexibility in exploiting visibility bias and social signals. Their static and dynamic properties are often studied by assuming that consumers follow a multinomial logit model and try exactly one product. In this paper, we study how to generalize existing results to a more realistic setting where consumers can try multiple products. We show that a multinomial logit model with continuation can be reduced to a standard multinomial logit model with different appeal and product qualities. We examine the consequences of this reduction on the performance and predictability of the market, the role of social influence, and the ranking policies.

■ MB-12

Monday, 10:30-12:00 - 206B

Financial mathematics 1

Stream: Financial mathematics and OR
Invited session
Chair: Norio Hibiki

1 - An EBIT-based structural credit risk model using Bayesian estimation
Rei Yamamoto, Kazunari Sawada

Various credit risk models have been proposed such as a structural model, statistic model and so on. These models need sufficient financial data or stock price data to estimate probabilities of default. Therefore, we cannot estimate probabilities of default of companies without sufficient financial data such as private companies in emerging countries. Then we construct an EBIT-Based structural credit risk model for estimating probabilities of default of companies without sufficient financial data. In this model, it is possible to estimate probabilities of default by using only profit (EBIT), debt and risk premium of companies. Moreover, we propose to use Bayesian estimation to the drift and volatility of profit of the companies in order to make stable estimation with insufficient data. In the computational experiments, we show that our proposed method improves the estimation accuracy of the probabilities of default.

2 - Stress testing model based on supply chain relationships
Muneki Kawaguchi

Stress testing has become an important risk management tool for financial entities. In CCAR, which is one of the public stress testing schemes, FRB releases three stress scenarios which are estimates of macroeconomic value such as GDP, interest rate, currency rate and so on. Financial entities estimate their loss amounts if the stress scenario occurs. We propose a new stress testing model for credit portfolio using supply chain information. It is important to consider the correlations for risk management. The stock price correlations are often used as the proxies for correlations between corporates. As far as I know, supply chain information isn't used to calculate credit portfolio risk amounts. The supply chain information is direct relationships between corporates, so the model can capture their interactions in detail. We discuss the advantages of our model over the stress testing model based on the stock price correlations. Therefore, we investigate about their credit risk from a standpoint of network analysis. The network analysis is developing rapidly in the areas of economic network, social network, and biological network. The economic shock is propagated through the economic network, so the economic contagion is crucial for risk management. We formulate the relationships and the economic contagion in the model.

3 - CAPM on segmented markets: A synthesis, an extension and an application to Islamic financial markets
Ahmed Badreldin, Bernhard Nietert

The theoretical literature on segmented markets deals only with single segmented markets with respect to risky assets but has so far ignored single segmented markets with respect to the riskless asset (markets where some investors cannot invest in the riskless asset), and double segmented markets (markets where some investors can neither invest in some risky assets nor in the riskless asset at the same time). From a practical perspective, single segmented market models with respect to risky assets cannot handle the field of Islamic financial markets where investors are not allowed to invest in risky assets that are not Shariah compliant or in assets bearing a riskless interest. — Islamic financial markets have nowadays, however, grown into relevant players on the market. For that reason, we fill the literature gap by developing a tailored CAPM for both double segmented markets as well as single segmented markets with respect to the riskless asset based on the Lintner (1977)/Rubinstein (1973) segmented market's CAPM. In addition we illustrate empirically that segmented market adjustments to the CAPM are economically relevant. The mistakes that occur when market segmentation is overlooked were found to be economically as well as statistically significant in more than 75% of all cases we study.

4 - Multi-period optimization model with downside risk for market order execution
Norio Hibiki, Shunichi Takenobu

When fund managers or traders in the financial institutions trade a large volume of a stock, the trading volume might impact the stock price. Therefore, we need to develop the intraday execution strategy in consideration of the price impact cost and market timing risk. This paper discusses a multi-period optimization model with downside risk for market order execution. At first, we formulate the hybrid model with downside risk in the simulated path approach for market order execution, and develop the iterative algorithm to solve the problem. We find the optimal volumes of backlogged order are close to a short-butterfly-shaped function of the cumulative execution cost. The function form is nearly V-shaped at a point, and it becomes gradually flat when the cost is far from the kinked point. Second, we propose a piecewise linear (PwL) model with the short-butterfly-shaped function, which kinked point is derived using the analytical model. We compare the two kinds of models through numerical experiments, and examine the usefulness of the models. We solve the six-period problem with 50,000 paths as a base case. We conduct the sensitivity analysis for different coefficients of risk averse and market power, and the number of successive closed intervals of a PwL function. In addition, we examine the problems for the different number of periods, and find the computation time can be drastically reduced using the PwL model, compared with the hybrid model.

■ MB-13

Monday, 10:30-12:00 - 207

Performance and efficiency evaluation

Stream: Recent advances in performance and efficiency evaluation
Invited session
Chair: *Adel Hatamimarbini*

1 - Gangs elimination in DEA cross-evaluation
Gholam R. Amin

In the data envelopment analysis (DEA) cross-efficiency evaluation, a group of decision making units (DMUs) can significantly influence the cross-evaluation in favour of some DMUs. This is called as the "ganging-together" phenomenon in the DEA cross-evaluation. This paper proposes a new methodology for gangs elimination in the DEA cross-evaluation. It is shown that eliminating gangs can increase the fairness of cross-evaluation and generate more diversified top performing DMUs. An application in stock market selection is used to show the usefulness of the proposed method.

2 - A DEA-DA approach for classifying multi-group observations
Mehdi Toloo, Adel Hatamimarbini

Data envelopment analysis-discriminant analysis (DEA-DA) exploits the methodological and analytical advantages of two models at once. DEA-DA identifies the overlap between two groups of observations (firms) along with determining the group classification of a newly sampled observation. However, it may be of interest to have more than two groups of observations in the analysis. In this paper, we propose a new DEA-DA technique for classifying an observed data set into several groups of observations. We additionally present the applicability of our approach by predicting the group membership of a set of suppliers that play a tremendous role in a sustainable supply chain.

3 - Dual-role factors for imprecise data envelopment analysis
Adel Hatamimarbini

In conventional data envelopment analysis (DEA), the observed inputs, outputs and dual-factors are assumed to be precise. However, we often observe imprecise and ambiguous data in practice. In this paper, we present an imprecise DEA model in the presence of dual-role factors to deal with the imprecise data. The resulting models are the mixed binary integer programming models that supply the best possible relative efficiencies from the optimistic and pessimistic viewpoints. After some theoretical discussions, the proposed models are illustrated with a numerical example.

■ MB-14

Monday, 10:30-12:00 - 305

Bayesian mechanism design via duality

Stream: Algorithmic/computational game theory
Invited session
Chair: *Matthew Weinberg*

1 - Simple mechanisms for subadditive buyers via duality
Yang Cai

We provide simple and approximately revenue-optimal mechanisms in the multi-item multi-bidder settings. We unify and improve all previous results, as well as generalize the results to broader cases. In particular, we prove that the better of the following two simple, deterministic and Dominant Strategy Incentive Compatible mechanisms, a sequential posted price mechanism or an anonymous sequential posted price mechanism with entry fee, achieves a constant fraction of the optimal revenue among all randomized, Bayesian Incentive Compatible mechanisms, when buyers' valuations are XOS over independent items. If the buyers' valuations are subadditive over independent items, the approximation factor degrades to O(log m), where m is the number of items. We obtain our results by first extending the Cai-Devanur-Weinberg duality framework to derive an effective benchmark of the optimal revenue for subadditive bidders, and then analyzing this upper bound with new techniques.

2 - A simple and approximately optimal mechanism for a buyer with complements
Ophir Friedler, Matthew Weinberg, Michal Feldman, Inbal Talgam Cohen, Alon Eden

We consider a revenue-maximizing seller with m heterogeneous items and a single buyer whose valuation v for the items may exhibit both substitutes and complements. We show that the better of selling the items separately and bundling them together guarantees approximately optimal revenue, where the approximation ratio corresponds exactly to a measure on the degree of complementarity that we define. Note that this is the first approximately optimal mechanism for a buyer whose valuation exhibits any kind of complementarity, and extends the work of Rubinstein and Weinberg [2015], which proved that the same simple mechanisms achieve a constant factor approximation when buyer valuations are subadditive, the most general class of complement-free valuations. Our proof is enabled by the recent duality framework developed in Cai et al. [2016], which we use to obtain a bound on the optimal revenue in this setting. Our main technical contributions are specialized to handle the intricacies of settings with complements, and include an algorithm for partitioning edges in a hypergraph. Even nailing down the right model and notion of "degree of complementarity" to obtain meaningful results is of interest, as the natural extensions of previous definitions provably fail.

3 - The FedEx problem
Kira Goldner, Amos Fiat, Anna Karlin, Elias Kousoupias

Consider the following setting: a customer has a package and is willing to pay up to some value v to ship it, but needs it to be shipped by some deadline d. Given the joint prior distribution from which (v, d) pairs are drawn, we characterize the auction that yields optimal revenue, contributing to the very limited understanding of optimal auctions beyond the single-parameter setting. Our work further demonstrates the importance of 'ironing' in revenue maximization, helping to illustrate why randomization is necessary to achieve optimal revenue. Finally, we strengthen the emerging understanding that duality is useful for both the design and analysis of optimal auctions in multi-parameter settings.

4 - A duality based unified approach to Bayesian mechanism design
Matthew Weinberg, Yang Cai, Nikhil Devanur

We provide a unified view of many recent exciting developments in Bayesian mechanism design, including the black-box reductions of Cai et. al., simple mechanisms for additive buyers [Hart and Nisan, Li and Yao, Babaioff et al.], and posted-price mechanisms for unit-demand buyers [Chawla et al., Kleinberg and Weinberg]. Additionally, we show that viewing these three previously disjoint lines of work through the same lens allows us to improve upon each in several directions. First, our work provides a new and transparent duality framework for Bayesian mechanism design, which naturally accommodates multiple agents, and arbitrary objectives and feasibility constraints. Using this, we prove that either a posted-price mechanism, or the VCG mechanism with per-bidder entry fees is a constant-factor approximation to the optimal Bayesian IC mechanism whenever buyers are unit-demand or additive, unifying previous breakthroughs of Chawla et al. and Yao. In addition, we improve the approximation factor in Yao's work from 69 to 8. Finally, we show that this view also leads to improved structural characterizations in the Cai et. al. framework.

■ MB-15

Monday, 10:30-12:00 - 307A

Interior point methods 1

Stream: Continuous optimization (contributed)
Contributed session
Chair: Aurelio Oliveira

1 - Further development of column generation with the primal-dual interior point method
Jacek Gondzio

Advantages of interior point methods (IPMs) applied in the context of column generation will be discussed. Some of the many false views of the combinatorial optimization community on interior point methods will be addressed and corrected. Several recent developments will be presented. The talk will gently introduce some of the relevant mathematical optimization developments and will also briefly mention our software called PDCGM (Primal-Dual Column Generation Method) available for research use: http://www.maths.ed.ac.uk/ gondzio/software/pdcgm.html

2 - An interior algorithm for solving nonlinear second-order cone complementarity problems
Julio López, Miguel Carrasco, Hector Ramirez

A new feasible direction algorithm for solving nonlinear second-order cone complementarity problems is presented. Given an interior point to the feasible set, the proposed algorithm computes a feasible and descent direction for an appropriate potential function. The search direction is computed by solving a Newton's system modified. Then, a line search along the search direction finds a new feasible point that has a lower value of the potential function. Repeating this process, the algorithm generates a feasible sequence with a monotone decreasing of the potential function. Under mild assumptions we prove global convergence of the present algorithm. Numerical testing over some test problems is carried out and reported.

3 - Optimized choice of parameters in interior-point methods for linear programming
Aurelio Oliveira, Luiz-Rafael Santos, Fernando Villas-Bôas, Clovis Perin

In this work, we propose a predictor-corrector interior point method for linear programming in a primal-dual context, where the next iterate is chosen by the minimization of a polynomial merit function of three variables: the first is the steplength, the second defines the central path and the third models the weight of a corrector direction. The merit function minimization is performed by restricting it to constraints defined by a neighborhood of the central path that allows wide steps. In this framework, we combine different directions, such as the predictor, the corrector and the centering directions, with the aim of producing a better one. The proposed method generalizes most of predictor-corrector interior point methods, depending on the choice of the variables described above. Convergence analysis of the method is carried out, considering an initial point that has a good practical performance, which results in Q-linear convergence of the iterates with polynomial complexity. Numerical experiments using the Netlib test set are made, which show that this approach is competitive when compared to well established solvers, such as PCx.

■ MB-16

Monday, 10:30-12:00 - 308A

Operations finance interface 1

Stream: Operations finance interface
Invited session
Chair: Thomas Archibald

1 - Optimal investment decisions for recovery from disruptions in the decentralized supply chains
Nader Azad, Elkafi Hassini, Manish Verma

In this paper, we investigate the optimal supplier's and buyer's reactions to supply disruption. Upon disruption, the supplier loses the supply during the recovery period. Given a delivery time contract between the supplier and buyer, the supplier can make an investment to decrease the recovery time to benefit both parties. If the supplier's capacity is recovered after the delivery time, the supplier should pay a penalty cost to the buyer for each unit of lost sale demand and for the amount of time that the supply is delayed. Also, similar to the supplier situation, the buyer incurs a penalty cost for each unit of lost sale demand and for the amount of the waiting time. Because the supplier can decrease the recovery completion time, the buyer may offer a financial subsidy incentive to the supplier (sole sourcing with a financial subsidy incentive strategy) or source from two suppliers (dual sourcing strategy). In this study, we investigate the role of building long term supplier relationships, through joint investment programs, in mitigating the impact of supply disruptions. We present two Stackelberg game models to highlight optimal buyer's and supplier's decisions under the mentioned strategies We also find the financial incentives levels that would coordinate the two-party supply chain. Finally, we compare the two strategies and characterize the buyer's preference as a function of the model parameters.

2 - Harvest decisions of budget-constrained farmers
Anne Lange

Most of our vanilla is produced in Madagascar by farmers. The cultivations are small and the individual farmers sell their vanilla through intermediaries to large exporters. Weather conditions heavily impact the vanilla harvest. World market prices for vanilla are unstable and depend strongly on the vanilla supply. This study presents an analytical model for the specific situation in this value chain: As vanilla prices are currently high, the theft of vanilla pods from the plantations has increased substantially. Hence, farmers harvest vanilla early and vacuum pack it until the selling season. This early harvested vanilla is of inferior quality so that it does not meet the exporters' expectations. Results include that the farmer's budget constraint is of high relevance for his decision to harvest early: The tighter his constraint, the more he is forced to act risk-averse and secure his vanilla. Quite contrary to intuition, increased wholesale prices paid by the exporters will not induce farmers to increase the quality of their products.

3 - Supply chain networks and cascading failures
John Birge

The structure of supply chain networks has a differential impact on the network of firms depending on their position in the network. Changes in the environment, such as borrowing rates and overall consumption, can impact this structure and the resilience of the network to disruptions. This talk will discuss models of these impacts on failure cascades and network fragility.

■ MB-17

Monday, 10:30-12:00 - 309A

TSP and VRP

Stream: Discrete optimization - Computational methods
Invited session
Chair: Stefan Ropke

1 - Solving time-dependent traveling salesman problem with time windows with dynamic discretization discovery
Duc Minh Vu, Natashia Boland, Mike Hewitt, Martin Savelsbergh

In this talk, we explore a study for solving the Traveling Salesman Problem with Time Windows (TSPTW) and variants in a context that considers time-dependent traveling time and time-dependent travel costs. To tackle the issue of time-dimension, we explore an approach in which the strength of an extended IP formulation is exploited without explicitly creating the complete formulation. The key to the approach is that it discovers exactly which times are needed to obtain an optimal, continuous-time solution, in an efficient way, by solving a sequence of (small) IPs. The IPs are constructed as a function of a subset of times, with variables indexed by times in the subset. They are carefully designed to be tractable in practice, and to yield a lower bound on the optimal continuous-time value. Once the right (very small) subset of times is discovered, the resulting IP model yields the continuous-time optimal value. The contribution of the study includes: (1) a set of properties, lemmas, and algorithms that allow to build and maintain partially time-expanded lower bound networks for the time-dependent TSPTW, (2) an algorithmic framework that exploits proposed results, and ensures the convergence to optimal solutions, (3) a comprehensive evaluation to assess the performance of the framework for travel-cost and make-span time-dependent TSPTW. Our experiment results indicate that the method is competitive with existing method for time-dependent and time-independent problems.

2 - On solvable cases of the shortest TSP-path problem
Vladimir Deineko

In our presentation we describe new polynomially solvable cases of the shortest TSP-path problem. In the TSP-path problem one looks for the shortest Hamiltonian path (not cycle, like in the standard TSP). While there are already quite a few known polynomially solvable cases of the standard TSP, the list of known easy cases for the shortest TSP-path problem is very short. We describe new exponential size neighbourhoods, where the optimal solutions for some specially structures cases can be found. These neighbourhoods can be searched in polynomial time.

3 - Quality of bound versus running time of the branch-and-bound algorithm: A computational experiment
Stefan Ropke

Integer programming (IP) problems are typically solved using a variant of the branch-and-bound method (e.g. branch-and-cut) where dual bounds are computed using the linear programming (LP) relaxation of the IP model. It is well known that the strength of the LP relaxation has a large impact on the size of the branch and bound tree and on the running time of the algorithm. It is also well known that it sometimes pay off use a formulation with a weaker LP bound compared to using a stronger formulation if the weak LP bound can be computed much faster. In this talk, we investigate this subject through computational experiments. We study a number of formulations for the asymmetric traveling salesman problem and the unit demand vehicle routing problem. We apply each formulation to a large number of randomly generated instances of different sizes. We then attempt, for each formulation, to derive a formula for the expected running time as a function of instance size. This formula is derived using regression analysis. Assuming that these formulas represent the true expected running we can then rank the formulations according to their expected running for different instance sizes. We note that the comparison only makes sense for the population of instances that the random instance generator samples from and we investigate the impact of changing the instance generator to sample instances from a (fundamentally) different population of instances.

■ MB-18

Monday, 10:30-12:00 - 2101

Enumeration problems and applications 1

Stream: Game theory, discrete mathematics and their applications
Invited session
Chair: Yasuko Matsui

1 - On safe sets in graphs
Yasuko Matsui

A safe set of a graph G = (V,E) is a non-empty subset S of V such that for every component A of G[S] and every component B of G[V - S], we have |A||B| whenever there exists an edge of G between A and B. In this talk, we show that a minimum safe set can be found in polynomial time for trees. We then further extend the result and present polynomial time algorithms for graphs of bounded treewidth, and also for interval graphs. We also study the parameterized complexity of the problem. We show that the problem is xed-parameter tractable when parameterized by the solution size. Furthermore, we show that this parameter lies between tree-depth and vertex cover number.

2 - On the enumeration of chequered tilings in polygons
Takashi Horiyama, Hiroaki Hamanaka, Ryuhei Uehara

The Tokyo 2020 Olympic and Paralympic Games Emblems are called 'harmonized chequered emblems.' They are composed of three kinds of rectangles. The rectangles are derived from three kinds of rhombuses of the same edge length, and the emblems can be seen as tilings of the rhombuses in a dodecagon. In this talk, we will show a bijection from the set of all tilings in a 2n-gon to a certain set of intersecting strings, and enumerate all such tilings. In the enumeration algorithm, we represents intersecting strings by an amidakuji (i.e., a ladder lottery).

3 - Enumerating all 2-edge-connected subgraphs
Katsuhisa Yamanaka, Takashi Hirayama, Hiroki Kaga, Naoki Katoh, Yasuaki Nishitani, Toshiki Saitoh, Kunihiro Wasa

We consider the problem of enumerating all 2-edge-connected subgraphs of a given graph. In this paper, we propose an algorithm that enumerates all 2-edge-connected subgraphs in polynomial time for each. The algorithm is based on the reverse search by Avis and Fukuda. First, we define a forest structure on a set of 2-edge-connected subgraphs of a given graph G such that (1) the roots are simple cycles in G, (2) each node corresponds to a 2-edge-connected subgraph, and (3) each edge corresponds to a parent-child relationship between two 2-edge-connected subgraphs. Then, by traversing the forest, we enumerate all the 2-edge-connected subgraphs. This is motivated by the problem of finding evacuation routes of road networks in time of disaster. In a time of disaster, it is easy to imagine that many roads are broken. Hence, we are required to ensure "multiple" evacuation routes to a shelter. In the situation that we know only one route between the current position to a shelter, nobody can ensure that the route can be passed through in safety. From this point of view, the problem of finding subgraphs with highly connected is important, since high connectivity of graphs ensure multiple routes between two points. In this paper, we focus on 2-edge-connected subgraphs as highly connected subgraphs.

4 - Enumerating floorplans
Shin-ichi Nakano

Given an axis-aligned rectangle R and a set P of n points in R we wish to partite R into a set S of n+1 rectangles so that each point in P is on the common boundary between two rectangles in S. We call such a partition a feasible floorplan of R with respect to P. Intuitively P is the locations of columns and a feasible floorplan is a floorplan in which no column is in a proper inside of a room. (However columns can be on the common wall between rooms.) In this talk we give an efficient algorithm to enumerate all feasible floorplans of R with respect to P.

■ MB-19

Monday, 10:30-12:00 - 2102AB

Business analytics 1

Stream: Business analytics
Invited session
Chair: *Wouter Verbeke*
Chair: *Dries Benoit*
Chair: *Kristof Coussement*

1 - Profit-based classification and feature selection with support vector machines: An application in credit scoring
Sebastian Maldonado, Cristian Bravo, Julio López, Juan Perez

Support Vector Machine (SVM) is a powerful classification approach that can be useful for decision support systems given its superior performance compared to traditional strategies, like logistic regression. This method, however, is not designed to take into account profit-related issues. In particular, it can neither identify the most relevant features used for the classifier construction, nor incorporate profit measures in the classifier construction. In this work we propose a profit-driven approach for classifier construction and simultaneous variable selection based on Support Vector Machines. The main goal is to incorporate business-related information such as the variables' acquisition costs, the type I and II error costs, and the profit generated by correctly classified instances into the modeling process. Our proposal incorporates a group penalty function in the SVM formulation in order to simultaneously penalize the variables that belong to same group (the L-infinity norm), assuming that companies often acquire groups of related variables for a given cost rather than acquiring them individually. This function is combined with the Tikhonov and LASSO regularization functions, leading to two SVM formulations for classification and embedded feature selection. The proposed framework was studied in a credit scoring problem for a Chilean bank, leading to superior performance with respect to business-related goals.

2 - A closer look at voting methods for cost-sensitive ensembles
George Petrides, Wouter Verbeke

Cost-sensitive prediction models have emerged as an alternative in scenarios where different types of prediction errors bear different costs. For example, incorrectly predicting a fraudulent credit card transaction as legitimate is more costly than the other way around. Instead of just looking at a single model, Ensembles such as Bagging, AdaBoost, Random Forests, and their cost-sensitive variants, combine the outcome of several models in hope to get a more accurate prediction. The aim of this work is to closely investigate all possible ways of doing so, also known as ensemble voting, and compare their performance using large and imbalanced datasets.

3 - Profit driven uplift modeling
Floris Devriendt, Wouter Verbeke

In order to save costs, marketers often utilise traditional response modelling to target only those customers that are likely to respond to the marketing campaign. However, these models fail to differentiate between customers who respond favourably because of the campaign and customers that respond favourably on their own accord, regardless of the campaign. Uplift modelling aims to establish the difference in customer behaviour because of a specific treatment that is given to the customer. In previous work, an extensive literature review and a benchmarking study has been done by the authors, grouping together all techniques from the literature and testing the performances of most of these techniques on several real-world datasets. In this paper we cover the results of the benchmarking study and highlight a problem regarding the evaluation of different uplift modelling techniques. Although different evaluation techniques exist to evaluate the performance of uplift models, the interpretability of the metrics is not so intuitive. Therefore we propose aprofit-driven approach towards uplift modelling which takes into account the costs of the campaign and the expected benefits. Our profit-driven approach allows us to identify the customers who are both highly influential and beneficial for a campaign. This approach allows for clear and interpretative knowledge to be used in future business decisions when setting up a new campaign.

4 - A profit-based approach for evaluating business-oriented regressions
Cristian Bravo, Wouter Verbeke

When estimating regression problems in a business environment, it is common practice to evaluate them using statistical measures, such as the Mean Square Error or the Mean Absolute Percentage Error. In this presentation, we argue that this is not enough within a financial or business-oriented context, since the profits and costs of any given solution can have a greater impact on the application of the model. Tools such as the H-measure (Hand, 2009) and the EMP measure (Verbraken et al., 2014) have shown this to be the case in credit scoring and in customer churn. Our proposal develops a profit-based measure for evaluating regression problems that are subject to estimation errors and random shocks, and is calculated by separating the costs and benefits of applying any given model on the profits that arise from the impact on profits of both the output of the model and the estimation error. These two quantities (errors and outputs) define a parametric profit surface, which can be regularized and adjusted by random effects, constructing a well-behaved function. The surface then serves as input for an expected profit measure, estimated as the volume under the surface. We evaluate the measure, dubbed the average utility in regression, (AUR), on a credit risk loss-given-default datasets and conclude that the measure is an effective tool to estimate the impact of profits on regression models.

■ MB-20

Monday, 10:30-12:00 - 2103

Realistic production scheduling

Stream: Scheduling: Theory and applications
Invited session
Chair: *Ruben Ruiz*
Chair: *Imma Ribas*

1 - Improved iterated greedy procedures for the distributed permutation flowshop problem
Ruben Ruiz, Quan-Ke Pan, Bahman Naderi

Scheduling is an important stage in productions operations and management. Optimized scheduling can pave the way for efficient factories and increased margins. Among scheduling problems, flowshop scheduling has been profusely studied in the scientific literature since the middle 1950s. The distributed permutation flowshop problem is a generalization of the regular flowshop in which n jobs have to be processed in m machines that are disposed in series in the manufacturing floor of a factory. Each job has to go through each machine in the same order. The distributed extension models a real situation which appears in larger companies which operate many production facilities. With this consideration there is an additional decision dimension so as to which factory each job should be assigned to. As a result, in the distributed permutation flowshop problem there are f factories and one has to first decide the job to factory assignment and then to schedule all jobs at each factory. This generalized flowshop was first proposed in 2010 and it has attracted a good deal of interest since. We present improved Iterated Greedy methods based on new destruction and reconstruction operators, local search procedures and acceptance criteria. The resulting procedure has been carefully calibrated and tested over a large computational benchmark. Statistical tests show that we are able to produce state-of-the-art results for the makespan minimization criterion.

2 - A metaheuristic algorithm for the unrelated parallel machine scheduling problem with additional resources
Eva Vallada, Fulgencia Villa, Luis Fanjul

In this work, a metaheuristic algorithm is proposed for the unrelated parallel machine scheduling problem with additional resources and the objective to minimise the maximum completion time or makespan. Both, processing times of the jobs and resource consumption of the jobs, are machine dependent. The proposed method starts from the best solution obtained by a set of constructive methods. After the construction, different local search procedures are applied in order to improve the solution. A benchmark of instances is also proposed considering small, medium and large instances as well as different ways to generate the processing times and the resource consumption: uniform and correlated distributions. An exhaustive experimental evaluation is carried out using the proposed benchmark, comparing the results against the most effective heuristics proposed for the same problem. Moreover, results are analysed by means of statistical analysis in order to identify which method shows the best performance.

3 - Approaching scheduling with automatic algorithm design
Pedro Alfaro-Fernandez, Ruben Ruiz, Federico Pagnozzi, Thomas Stützle

Scheduling is a very important topic for many industries. When complex scheduling problems grow in size so as to meet reality, researchers tend to resort to metaheuristics i.e. generalist computer methods that solve these problems approximately in a relatively small amount of computation time. Metaheuristic design relies on researcher expertise but many times this design is more creative than scientific. This process has produced great results in the past, but has some drawbacks like tightly problem specific metaheuristics or challenges in reproducibility of results, among many others. Recently, there has been a lot of research effort in a completely different and novel approach: Automatic Algorithm Design (AAD). AAD is basically a meta-metaheuristic that gathers together key components that mingled in specific order and structure compose a metaheuristic aimed to perform well in a given problem. It is like algorithms constructing algorithms. We apply ADD to the Hybrid Flow Shop problem, a realistic scheduling problem that needs compromises between abstraction and specialization. We have carried out a comprehensive computational campaign considering three different optimization objectives, as a change in the objective results in a change on the solution space topology. Even though we only have preliminary results, we have proven that ADD can generate competitive algorithms that even surpass the state-of-the-art after thorough comparisons.

4 - Simulation-optimization scheme for solving a real case of a ready mixed concrete dispatching problem
Cristian Cortes, Mauricio Cerda, Zdenko Koscina, Pablo A. Rey

At the level of the whole industry of the production of concrete in Chile, the low punctuality of deliveries of ready mixed concrete is an issue not well solved. This is definitely a relevant factor affecting considerably the productivity of the construction sector in the country. In this presentation, we will show a simulation-optimization scheme developed to solve the dynamic dispatching of ready mixed concrete faced by a major concrete producer in Santiago, Chile. In a first stage, we show the detailed description of the order fulfillment process, from the customers' requests, order taking, scheduling of specialized trucks and dispatch from different production plants spread over the city, where the concrete is produced and the trucks are immediately loaded for delivery to the final client, which must happen in a very limited time from the preparation of the concrete. The whole problem is dynamic and subject to different sources of uncertainty. We are proposing a simulation scheme to model the entire supply chain, identifying the potential inefficiencies where we formulate and optimize key problems, mainly in the processes of assignment of different orders to plants where the concrete must be elaborated, and the scheduling of specific trucks to fulfill those orders timely, noting that such scheduling is in essence multi-trip, and therefore, synchronization is a relevant issue to deal with in the entire solution approach.

■ MB-21
Monday, 10:30-12:00 - 2104A

Maritime optimization 1

Stream: Port operations
Invited session
Chair: Judith Mulder

1 - Port competition in Northwestern Europe: A case study
Nemanja Milovanovic

For a container terminal operator it is always important to stay on top of call size development and port call frequency to stay ahead of competitors. This is especially true with the emergence of the ultra large container ship (ULCS), as the call size is likely to increase, which may strain terminal operators. On top of that, we also expect the use of ULCSs to influence vessel routing, and port call frequency. In this research, we investigate these suspicions by doing a case study in port competition for Northwestern Europe, where we focus on various factors that we suspect may influence carriers' liner network designs, such as fuel price and fluctuations in demand. To this end, a mathematical model is used to construct an optimal liner network, given a certain scenario as input. In this model we do not only take into consideration demand at ports, but we also take into account freight demand in certain Hinterland regions in the Netherlands and Germany, as we suspect that this demand also has an impact on which port is called at in the liner network.

2 - Simultaneous optimization of speed and buffer times in liner shipping
Judith Mulder, Willem van Jaarsveld, Rommert Dekker

Transport companies often have a published timetable. To maintain timetable reliability despite delays, companies include buffer times during timetable development, and adjust the traveling speed during timetable execution. We develop an approach that can integrate decisions at different time scales (tactical and operational). We model execution of the timetable as a stochastic dynamic program (SDP). An SDP is a natural framework to model random events causing (additional) delay, propagation of delays, and real-time speed adjustments. However, SDPs alone cannot incorporate the buffer allocation, as buffer allocation requires to choose the same action in different states of the SDP. The objective is finding the buffer allocation that yields the SDP which has minimal long run average costs. We derive several analytical insights into the model. We prove that costs are joint convex in the buffer times, and develop theory in order to compute subgradients. Our optimal algorithm for buffer time allocation is based on these results. Our case study considers container vessels sailing a round tour consisting of 14 ports based on Maersk data. The algorithm finds the optimal timetable in less than 80 seconds for realistic problem instances. The optimal timetable yields cost reductions of about six to ten million USD per route per year in comparison to the current timetable.

3 - Industrial and tramp ship routing - Neighborhoods and metaheuristics
Gabriel Homsi, Rafael Martinelli, Thibaut Vidal

In this work, we focus on a rich class of Industrial and Tramp Ship Routing and Scheduling problems (ITSRSP) which extends the Pickup and Delivery Problem with Time Windows (PDPTW) with a heterogeneous fleet, compatibility constraints, different ship starting points and selection of services. This class of problems is connected with important applications in ship transportation. It presents a complex combination of attributes: the interplay of a heterogeneous fleet with the selection of services and pickup and deliveries requires to jointly optimize several decision sets. Hence, from a heuristic standpoint, a careful design of neighborhood searches is essential. To solve these problems, we propose a Hybrid Genetic Search with Advanced Diversity Control (HGSADC). It extends the metaheuristic of Vidal et al. (2013) with problem-specific crossover and local search operators. We tailor traditional vehicle routing neighborhoods to deal with pairs of vertices and block structures (segments of a route with no open pickup and delivery pairs). We use pruning techniques that allow the intelligent exploration of a linear fraction of quadratic and cubic neighborhoods. Our move evaluations are performed in amortized constant time due to preprocessing and concatenation techniques. Our computational experiments demonstrate the good performance of the method, which retrieves high quality solutions for both the ITSRSP and PDPTW.

4 - A city logistics problem in a maritime urban area
Massimo Di Francesco, Teodor Gabriel Crainic, Enrico Gorgone, Paola Zuddas

This study is motivated by a problem of City Logistics arising in maritime urban areas. Consider a fleet of inbound containers at a port. Containers are filled with pallets, which must be delivered to their final destinations in the landside. Containers cannot be opened in the port because of the lack of space, and/or this operation is too costly or disallowed. Freight distribution is organized in a two-tiered structure: in the first tier, containers are moved from the port to satellites, where pallets are transhipped in smaller and environment-friendly vehicles, which move pallets to their final destinations in the second tier. In this study, each container is allowed to be unpacked at a satellite only. The planning of operations involves determining which routes are served by vehicles and which containers or pallets are carried in each echelon. We present a mathematical formulation for this problem and discuss possible solution methods. Preliminary computational tests will be presented, as well as viable solution methods.

■ MB-23

Monday, 10:30-12:00 - 2105

Optimization models for supply chains

Stream: Modeling and simulation of supply chains
Invited session
Chair: Sandra Eksioglu

1 - Decision-making under uncertainty to support the planning of biomass supply
Ignacio Blanco, Daniela Guericke, Juan Miguel Morales, Henrik Madsen

During the last years, the consumption of biomass to produce power and heat has increased due to the new carbon neutral policies. Nowadays, many generation units are operated with different types of biomass instead of coal or natural gas. Biomass is transported from the supplier to the consumption sites and the contracts with the suppliers are negotiated months in advance. This negotiation process involves many uncertainties from the energy producer's side. The demand for biomass is uncertain at the time of negotiation, and heat demand and electricity prices vary drastically during the planning period. Furthermore, the optimal operation of combined heat and power plants has to consider the existing synergies between the power and heating systems while always fulfilling the heat demand of the system. We propose a solution method using stochastic optimization to support the biomass supply planning for combined heat and power plants. Our two-phase approach combines mid-term decisions about biomass supply contracts with the short-term decisions regarding the optimal market participation of the producer to ensure profitability and feasibility. The risk of major deficits in biomass supply is reduced by including appropriate risk measures to the models. We present numerical results and an economic analysis based on a realistic test case.

2 - A multi-objective optimization model for designing resilient supply chain networks
Joshua Margolis, Kelly Sullivan, Scott Mason, Mariah Magagnotti

Supply chains evolve over time: they expand via construction and/or acquisitions, and contract via facility closures and/or cost-cutting decisions. We introduce decision support models and methodologies for making network design decisions that promote successful current and future supply chain operations. Businesses operate in an uncertain world, where decisions regarding supply chain network design must be made despite the possibility of unforeseen future events that may disrupt or damage the supply chain. In an effort to aid decision makers in designing supply chain networks that can operate well in an uncertain future, we present a deterministic optimization model that considers both supply chain costs and network connectivity as objective functions. Using our model, decision makers are able to evaluate several solutions with different cost and connectivity values, choosing the network configuration that best serves the needs of their company. Though our model is also applicable for companies expanding or contracting their supply chains internally, we demonstrate our model from the perspective of a company redesigning their current supply chain due to an upcoming corporate acquisition.

3 - Tax or subsidy? An analysis of environmental policies in supply chains
Xuan Zhao

This paper investigates the impacts of two environmental regulation policies—pollution abatement subsidy and pollution emission tax—to a supply chain where the manufacturer invests in a pollution abatement technology. We apply game theory analysis to the government-manufacturer-retailer triad. For welfare-maximizing government agencies, the subsidy policy offers greater incentives for the manufacturer to abate pollution and yields higher profits for channel members. However, when pollution abatement is very costly and production emissions are highly damaging, the tax policy should be implemented as the subsidy policy leads to lower social welfare and environmental performance. Furthermore, Caution should be exercised when implementing the subsidy policy as a "hazard zone" exists where the society suffers, which does not exist under the tax policy. For manufacturers, interestingly, improving pollution abatement efficiency does not always payoff even it is costless. The aforementioned results are robust to market competition. Also, the manufacturer always welcomes competition under the subsidy policy, but not necessary under the tax policy; each retailer always fares worse with competition. Finally, competition enhances social welfare under the tax policy, but cautions should be taken if the government intends to encourage competition under a subsidy policy.

4 - Evaluating the economic and environmental impacts of biomass cofiring with and without carbon capture technology
Sandra Eksioglu, Hadi Karimi

Biomass cofiring in conjunction with Carbon Capture and Storage (CCS) is shown to be an effective approach to achieve large scale reductions in greenhouse gas (GHG) emissions from coal-fired power plants. However, the associated costs are often higher than using only the conventional CCS approach. Thus, in absence of the appropriate governmental support and incentives, power plants may not find CCS commercially attractive. In this study we propose a bi-objective optimization model to investigate the economic and environmental impacts of integrating cofiring and CCS strategies in power plants. The economic objective function maximizes the profit-earning potential in the supply chain. This function captures the revenues acquired due to tax incentives and displacement of coal with biomass feedstock, as well as, investment (in cofiring and CCS technologies), transportation and processing costs. The environmental objective function minimizes the GHG emissions throughout the life cycle of bioenergy. We use chance constraints to capture the impact of the uncertainties of biomass availability and quality on supply chain's performance. We use an exact solution approach to identify the Pareto optimal solutions for this problem. This approach uses the criterion-space search method for biobjective mixed integer programs.

■ MB-24

Monday, 10:30-12:00 - 301A

Financial mathematics with applications in energy, environment and climate

Stream: Financial mathematics with applications in energy, environment and climate
Invited session
Chair: *Maria Teresa Vespucci*
Chair: *Yan Gao*
Chair: *Ceyda Yazici*

1 - Applying convex optimal power flow to distribution locational marginal pricing

Zhao Yuan, Mohammad Reza Hesamzadeh

Distribution locational marginal pricing (DLMP) is a key market mechanism to activate the flexibilities from distributed energy resources (DERs). In this paper, we propose to apply convex optimal power flow (OPF) model and hierarchical economic dispatch (HED) to address the practical challenges of implementing DLMP. Because DC OPF model is not valid in distribution network, the potential approach to calculate DLMP is using AC OPF which is nonconvex and NP-hard. To address the computational challenge, we propose to use second order cone programming (SOCP) to convexify AC OPF. The numerical results from various IEEE test cases show that the proposed convex AC OPF model is accurate. To address the communication challenge, we propose a HED mechanism based on the Benders decomposition algorithm. The dispatch task of transmission and distribution networks are assigned to transmission system operator (TSO) and distribution system operator (DSO) respectively. We define the concept of generalized bid function (GBF) as a unified communication format between TSO and DSO. Only GBF is required to be communicated from DSO to TSO in order to achieve global optimal dispatch. The convergence of HED is guaranteed by the convexity of the proposed convex AC OPF. A grid computing structure in GAMS is designed to accelerate the HED. By using the IEEE 342-node test case, the application of the proposed convex AC OPF and HED to calculate DLMP is demonstrated.

2 - Application of bootstrap to likelihood ratio test to detect multiple changepoints in small time series data

Ceyda Yazici, Ceylan Yozgatligil, Inci Batmaz

The detection of changepoints, structural changes or inhomogeneity in the time series is an important problem that should be discussed. This problem is studied in different fields such as meteorology, economics and finance. The changepoints can cause mean shift, sudden increase or decrease, or artificial trends in the series. The likelihood ratio test is used to test whether there is a changepoint in the series and it performs well in terms of detecting the exact location of the changepoint. If it is close to the beginning or end of the series, the performance of the test becomes worse in the case of a single changepoint. However, the application of bootstrap for dependent data improves the performance of the test in that case. In this study, the performance of the likelihood ratio test is tried to be improved by using bootstrap for dependent data and the results are discussed if there are multiple changepoints. The results are also compared with the widely used homogeneity test Standard Normal Homogeneity by using a simulation study.

3 - Economic analysis on renewable energy polices: The effects of cost function and market structure

Mari Ito, Ryuta Takashima, Makoto Tanaka, Yihsu Chen

Recently, increasing renewable energy (RE) is required to reduce greenhouse gas (GHG) emissions. Various countries have introduced policies for promoting RE, e.g., feed-in tariffs (FIT) and renewable portfolio standards (RPS). It has been analyzed from various aspects that how introducing RE policies impacts on economics. Hibiki and Kurakawa (2013) explored how RPS and FIT affect social welfare (SW) when damage cost function for non-renewable energy (NRE) production is a linear function and market structure is Perfect competition. Their findings indicated that RPS is superior to FIT when the rate of increase in marginal cost of GHG emissions is relatively high. Our study proposes economic analysis model which assumes quadratic damage cost function for NRE production and market structure of Cournot oligopoly. Our purpose is to clarify how differences of models impact on analysis results by comparing proposed model and Hibiki and Kurakawa model. We examine SW of FIT and RPS by bi-level model. For a lower level, generation outputs for RE and NRE producers are decided by maximizing their profits whereas for an upper level, the fixed price of FIT and the RPS requirement percentage are derived by maximizing a SW. Additionally, we evaluate how the rate of increase in marginal cost of GHG emissions affects SW by numerical analysis. We found that the SW of RPS is bigger than that of FIT regardless of the rate of increase in marginal cost of GHG emissions.

4 - Nonsmooth optimization approach to the real-time pricing for smart grid

Yan Gao

Smart grid is an electricity delivery system enhanced with communication facilities and information technologies. According to the real-time price, the users can improve the insulation conditions and try to shift the energy consumption schedule of their high-load household appliances to off-peak hours to achieving optimal allocation of resources. In this paper, we discuss the real-time pricing under the social utility maximization in smart grid. We adopt the utility function to reflect consumer's preferences and spending power, and set up the social utility model. We give some properties of the social utility model and adopt the shadow price as real-time price. In existing researches, dual method are used to solving this problem. But this method usually need to solve a series of unconstrained minimization problem, so the amount of computation is huge. According to Karush-Kuhn-Tucker condition, we set up a nonsmooth equations based on social utility model firstly. Then, we propose a new smooth approximating function based on the complementary theory which is more suitable to real-time pricing problem. The nonsmooth equations are shifted to smooth ones. The system of smooth equations is solved by quasi-Newton method. It is shown that the present method is effective by the simulation.

■ MB-25

Monday, 10:30-12:00 - 301B

OR and ethics 1

Stream: OR and ethics
Invited session
Chair: *Robyn Moore*
Chair: *Gerhard-Wilhelm Weber*

1 - Effects of corporate social performance on default risk: Structural model-based analysis on Japanese firms
Hitoshi Takehara

In this paper, we examine how firms' corporate social performance (CSP) is related to firm default risk. We estimate the default risk of a firm by employing the structural credit risk model first developed by Merton (1974). Using the model, we explain the theoretical linkage between CSP and the probability of default (PD). We find that CSP is positively associated with the PD of financially unconstrained large-capital firms. However, PD among those large-capital firms is extremely low, and CSP exerts little influence over default risk. Among small-capital firms, by contrast, CSP is negatively associated with PD. This implies that a higher degree of CSP alleviates the default risk of small-capital firms. These asymmetric CSP effects on PD can be explained by the difference in risk and profit reduction between large and small-capital firms. Financially constrained small-capital firms can reduce their PD and cost of debt by improving their CSP, although their CSR activities are detrimental to the profitability of the firm. Thus, managers of financially unconstrained small-capital firms should pay more attention to CSR activities to enhance trustworthiness in the capital market by mitigating social risk.

2 - A factor analysis of public opinion on nuclear power in Japan
Shohei Nagata, Ryuta Takashima, Noriaki Sakai, Itaru Takahashi, Makoto Funakoshi, Masayuki Tomiyama, Hiroshi Kimura, Kazuhisa Kawakami, Takeshi Iimoto

From a viewpoint of grasping public consciousness, the Japan Atomic Energy Relations Organization has investigated the public opinion for nuclear power from 2006 in order to conduct nuclear knowledge dissemination activities. We analyze the data for the polls by means of a factor analysis. We show hidden factors included in the image of the Japanese people for nuclear power. We also indicate what factors constitute the image for nuclear power with the factor. In addition, by observing secular changes of the factors, we confirm how the public awareness changes due to the impact of the Fukushima nuclear power plant accident at the time of the Great East Japan Earthquake that occurred in 2011. As a result, we find that the nuclear power for the Japanese people has six factors of "positive image", "negative image", "benefit recognition", "risk recognition", "difficulty in understand", and "complexity". It turns out that some people with "negative image" have a certain number that had negative feelings against nuclear power without thinking of benefits and risks. In terms of aging, we show that in 2011 the proportion of "negative image" and "risk recognition" have increased rapidly. The Japanese people also may be interested in benefits than risks in peacetime because their interests are shifting from "risk recognition" to "benefit recognition" from 2012, and similarly before 2011, their interests are suitable for "benefit recognition".

3 - Threads of validation in research through complementary use of TOC and other qualitative research methods
Robyn Moore

This paper describes an approach to conducting qualitative research that we have been experimenting with over the last decade through several postgraduate and action research projects. The paper aims to show how Theory of Constraints (TOC) developed for organisational research can be used in complementary fashion with other qualitative methods to strengthen the validity and ethics of both types of research. It stems from the need, when working with human systems, for ways of conducting such research with integrity. A multi-methodology approach has been developed iteratively by adopting and adapting TOC and other qualitative research tools. The paper describes our approach and illustrates this with examples from the specific projects. The combination of the two approaches has provided particular advantages for researchers who had no prior training in TOC or other qualitative methods. TOC helped by guiding the research design, data collection and analysis, and by clarifying the logic of argumentation, providing a clear structure in which to communicate and critique claims. Complementary qualitative research contributions include protocols on research ethics, participant selection, sampling, data collection and analysis, and using participants' voices. The complementary use of the two methods has provided threads of validation to strengthen the research process and enhance the outcomes. The approach is discernibly different from mainstream qualitative research.

■ MB-26

Monday, 10:30-12:00 - 302A

OR in health and life sciences

Stream: Probabilistc methods and simulation in health and life sciences
Invited session
Chair: *Hitoshi Hohjo*
Chair: *Masahiko Sakaguchi*

1 - An analysis of public policies and patient preferences on the healthcare system
Aydin Teymourifar, Onur Kaya, Gurkan Ozturk

In this study, we consider the public and private hospitals in the healthcare system of Turkey. We analyze the effects of public policies on the patients' preferences regarding hospital choices and the results of these choices on social utility and public spending. Public and private hospitals have different qualities and service levels and patients need to pay different amounts. Public hospitals, in general, are cheaper, but more crowded and offer lower quality service than private ones. In order to decrease the high waiting times in public hospitals and to offer better service, the government makes certain contracts with the private hospitals that will effect some of the patients' choices and increase the number of people going to the private hospitals instead of to the public ones. In these contracts, the government negotiates the prices that will be set by the private hospitals and also agrees to pay a certain amount per patient to these hospitals, which will decrease the amount that the patients need to pay when they go to private hospitals. As a result of this decrease in prices, more patients are directed to private hospitals leading to lower densities in public hospitals and a higher social utility in general. We analyze different contracts and try to obtain the optimal contract parameters considering the effects of these contracts on the public expenses, patients' satisfaction, waiting times in hospitals and payments made by the society in general.

2 - Prediction of hematologic cancer incidence among the aging society in Kanagawa, Japan
Masahiko Sakaguchi, Kayoko Katayama, Hiroto Narimatsu

Prediction of the number of incident cancer cases is very relevant for health planning purposes and allocation of resources. Owing to the increasing number of elderly "baby boomers" in Japan, the number of cancer patients is also expected to increase. Approximately 2 million baby boomers from nearby local areas are residing in metropolitan areas; hence, the geographical distribution of cancer patients will probably markedly change. We assessed the future number of hematologic cancer (HC) patients in different regions using estimates of the nation's population and Kanagawa Cancer Registry data. Kanagawa prefecture is a prefecture of Japan. To estimate future HC incidence for each region, we used an age-period-cohort model and a fixed 2010 rate model. In the fixed 2010 rate model, we multiplied the 2010 rate by the predicted population for each region according to age groups.

3 - The use of analytics to assess and improve logistics decisions in home health care services in a developing country
Elena Valentina Gutiérrez, Sebastian Cortes Zapata, Juan Sebastian Jaen

Home Health Care (HHC) is a worldwide growing medical service in which health institutions provide medical care for patients at their homes. These services are particularly important in developing countries where health care reforms have increased service coverage while affecting their quality. When providing the service, HHC managers face a set of logistics decisions that define the design of the system and its operation. Evidence shows that in most cases those decisions are made empirically, thus generating a sub utilization of scarce health resources, inefficiencies, and most importantly affecting patients safety. In this work we propose a model to measure the maturity of HHC providers to make logistics decisions through the adaptation of the Capability Maturity Model (CMM). The model is used to identify improvement opportunities and to prioritize them. Furthermore, we illustrate how analytics and quantitative methods can offer support to make better logistics decisions, and therefore, to provide better HHC services. The CMM model, an epidemiological profile identification, and a metaheuristics method are evaluated with a set of real HHC providers from a developing country in Latin America. Results allow identifying improvement opportunities and show that better logistics decisions can help to provide better HHC services.

4 - An integer program for the generation of balanced diets of minimum cost for elderly
Fernanda Salazar, Sandra Gutierrez

We study the case of generating diets for elderly patients at the "Hospital for Integral Attention to Elderly" in the hospitalization area as well as for outpatient area, in Quito. First, we estimate an individual's basal metabolic rate (BMR) and his daily nutritional requirements via the Harris-Benedict equation. Then, we consider the problem of balance the intake of nutrients. Such balance depends on the individual health condition of the elderly, where a patient could has more than one disease at a time. In this study, because of their relevance in number the cases attended historically at the Hospital, we consider four scenarios for the health condition of patients, namely: No Diabetes, Only Diabetes, Diabetes and obesity and Diabetes and hypertension. Every scenario sets the balance of nutrients that a diet must achieved. Afterwards, we introduce both the nutritional requirements and the diet's balance condition, into an integer linear program where the objective is to find the diet of minimum cost. The integer program is a version of the Stigler's Diet Problem that take into account not only the satisfaction of lower or upper bounds of nutrients but also their balanced intake, according to one of the four scenarios. Aditionally, the suggested diets are based on regional products. Finally, we present an analysis of computational results and conclusions for the problem.

■ MB-27

Monday, 10:30-12:00 - 302B

Behavioural issues in the practice of OR

Stream: Behavioural OR
Invited session
Chair: L. Alberto Franco

1 - Why pay attention to paths in the practice of environmental modelling?
Raimo P. Hämäläinen, Tuomas Lahtinen, Joseph Guillaume

Taking the "path perspective" helps to understand and improve the practice of modelling and decision making. A path is the sequence of steps taken in a modelling project. The problem solving team faces several forks where alternative choices can be made. These choices determine the path, together with the impact of uncertainties and exogenous effects. The concept of a path draws attention to the interplay of behavioral phenomena and the dynamics and the sequential nature of modelling processes. This helps understand the overall effect of the behavioral phenomena. We discuss phenomena that influence the problem solvers' choices at the forks in the modelling project. Situations are described where it can be desirable to re-direct the path or backtrack on it. Phenomena are identified that can cause the modelling project to get stuck on a poor path. A path checklist is developed for modelers to detect forks and reflect on the path of the modelling project. Our illustrations relate to environmental modelling processes. In these processes the number of critical forks can be particularly high and one can easily end up following different paths. This is due to problem complexity, high number of stakeholders, and multiple sources of uncertainties.

2 - The structure of problem structuring conversations: A boundary games approach
Jorge Velez-Castiblanco

There is a growing interest in studying the problem structuring microprocesses. This article studies those from the boundary games theory perspective. It involves viewing boundaries as the containers of different groups of ideas. These boundaries change in a language game through the use of language, actions, and, material objects. Tracing the evolution of boundaries shows different "streams" of ideas, that allows the construction of graphs. Those reveal an emerging structure of the problem structuring conversations. From a methodological perspective, this work contrasts two short sessions from a series of workshops constructing a value proposition for a group of consultants working in a university. The research expands concepts and ideas around how actors create rules of process and content in a session. It proposes three ways in which this is achieved in relation to how actor's communications bind the streams of conversations involved. 1) Branching opens subordinate streams of conversation. 2) Synthesizing produces a convergence of streams. Finally, 3) Shifting, changes the topic, while keeping elements of the old. It transforms the current stream of ideas. These kinds of operations mark pivotal points in the development of a session. These points are used to produce a general graph of the session structure. Understanding the structure can help practitioners navigate the emergent dynamics of the sessions.

3 - A comparison of PSM and non-PSM supported workshops: The creation and use of models
Isabella Lami, Elena Tavella

Applications of PSMs are extensively reported in the literature, however, their evaluation remains challenging. Moreover, scholars' disagreement on how to evaluate and compare PSMs constrains research that seeks to show whether certain PSMs are more useful than others and better than doing nothing. Drawing on scholars' suggestion to evaluate PSMs through a link between action, outcomes and context, we address this gap by adopting an exploratory, experimental research design to evaluate and compare three workshops supported by the use of (i) SCA, (ii) SSM and (iii) a non-PSM supported approach and report on the findings of a quantitative and qualitative analysis. These workshops were carried out with MSc students competent in the area of urban transformation. To evaluate the outcomes of the workshops we collected data in four ways: (i) questionnaires, (ii) video- and audio-records of the workshops, (iii) pictures of the workshop outcomes, and (iv) video- and audio-records of and notes taken during the reflective workshop and presentations made by the students. We placed the creation and use of models at the center of our analysis, which shows variation in the quality and usefulness of the three approaches depending on the issues at hand, the facilitation type and the outputs.

4 - Making OR practice 'visible': An ethnomethodological study of a facilitated modelling workshop
L. Alberto Franco, Christian Greiffenhagen

Empirical studies attempting to open the 'black box' of the practice of OR are beginning to appear in the literature, particularly within the area known as behavioural OR. Many scholars within this community share a commitment to both, empirically investigate what OR practitioners and users actually do when engaged in OR-supported processes, and evaluate what the effect of these 'doings' is. In this presentation, I treat real-time OR practice as an analytical problem, and use ethnomethodology to bring to the fore its material and interactional features for close examination. Using a video vignette drawn from a facilitated modelling workshop in which causal mapping was used with a top management team, I will first illustrate how an ethnomethodologically-informed perspective can reveal the ways in which OR-supported activity is practically accomplished by those involved, moment by moment, and with what effects. I will then discuss the potential contribution that these kinds of fine-grained studies make to the behavioural OR agenda, and outline some useful avenues for future behaviourally-inspired research of OR practice.

■ MB-28

Monday, 10:30-12:00 - 303A

Healthcare delivery and planning

Stream: OR in healthcare
Invited session
Chair: Patrick Hirsch

1 - A stochastic agent-based model with optimization strategies for nursing workforce planning
Mário Amorim Lopes, Álvaro Almeida, Bernardo Almada-Lobo

Human resources for health (HHR) are critical for delivering health care services. Since the health labor market faces many legal and regulatory rigidities, timely and adequate planning of HHR is necessary to ensure there will be enough practitioners to attend to the needs of the population. Nurses, in particular, are a cornerstone of health care services, with a shortage potentially leading to unmet care needs. To this purpose, system-level approaches, such as System Dynamics, have been used with reasonable success to generate forecasts and assess future needs. However, micro-level approaches allow for studying behavior at the level of an individual nurse, opening a whole new realm of research questions that may now be addressed. In this work we present a stochastic agent-based simulation model to forecast the Portuguese nursing workforce until 2050. Additionally, we use university vacancies as a policy lever for either increasing or decreasing the workforce size, and use the Monte Carlo method to experiment with objective functions capable of optimizing the workforce causing minimal disruption to universities.

2 - Patient survey of referral from one surgeon to another to reduce maximum waiting time for elective surgery and hours of over-utilized operating room time
Franklin Dexter, Ilana Logvinov, Elisabeth Dexter, Sorin Brull

Discrete-event simulation shows that if operating room (OR) cases are performed in underutilized time of 1 surgeon instead of overutilized time of another, OR costs or patient waiting are less. Use depends on patient perspective of shared decision-making for scheduling surgery. We presented questions with different waiting times. "Assume the consultant surgeon (i.e., the surgeon in charge) you met in clinic did not have time available to do your surgery within the next" period "but his/her colleague would have had time to do your surgery within the next" period. "Would you have wanted to discuss with a member of the surgical team (e.g., the scheduler) the availability of surgery with a different, equally qualified surgeon at Mayo Clinic who had time available within the next" period "on a date of your choosing?" Patients' choices for waiting time sufficient to discuss having another surgeon perform the procedure did not differ between those who had undergone lung resection or cholecystectomy (P=0.91). The % patients whose response to study questions was "4 days" were 58.8% (40/68) for lung resection and 58.2% (39/67) for cholecystectomy. The 97.5% two-sided confidence interval for median maximum wait was 4 days to 4 days. Thus, it appears medically paternalistic not to discuss with patients the option of another surgeon performing the procedure if surgery cannot be performed even within 1 week and an alternate surgeon has sooner OR time.

3 - The challenges of home health care routing and scheduling
Patrick Hirsch, Christian Fikar

This talk aims at providing a comprehensive overview of current work in the field of home health care (HHC) routing and scheduling with a focus on considered problem settings. Moreover, it presents an outlook on promising future research directions, which is also based on the knowledge of practitioners in HHC organizations. The talk concludes with showing issues the authors were faced with, when implementing their developed algorithms at HHC providers. In industrialized countries, the demand for HHC services is expected to rise significantly during the next years. Nevertheless, the planning of HHC services is still done manually in most HHC organizations. HHC routing and scheduling problems have gained substantial scientific interest over the past years. They consider a wide range of regulative and operational constraints as well as diverse objectives. Their formulations and solution procedures differ substantially in literature, since the problems originate from different national and regulatory settings. Important constraints in HHC include time windows, skill levels, working- and break time regulations, precedence, synchronization, uncertainty, or continuity of care. HHC staff may use different modes of transport like bike, bus, tram, metro, or car, which can also be combined. The literature presents solution methods for single- and multi-period HHC routing and scheduling problems that are based on heuristics, metaheuristics, matheuristics, and exact approaches.

■ MB-29

Monday, 10:30-12:00 - 303B

Military, defense and security applications 1

Stream: Military, defense and security applications
Invited session
Chair: René Séguin

1 - Modelling the population demographics of a new military occupation
Lynne Serre

Defence Research and Development Canada has developed a generic discrete-event simulation tool to model the recruitment, training, promotion and release of full-time military members. This paper discusses how the model was adapted to provide the Royal Canadian Navy with a tool to help manage risk as they navigate the merger of three technical trades and plan for future fleet requirements within this new occupation. Modelling approach and sample analyses will be presented.

2 - Optimal student allocation to timetables using dancing links and integer linear programming
Vivian Nguyen

Algorithms for optimal timetabling involve sequential allocation of students to courses and resources as the algorithm unfolds. In this paper, we propose a novel solution that is comprised of two distinct phases. We first enumerate all feasible course schedules, along with their costs, using a modified implementation of Knuth's Dancing Links technique for solving the exact cover problem. To our knowledge, the only prior use of this implementation has been to solve puzzles such as Sudoku and the N-Queens problem. This technique is able to handle complex timetabling problems, where the number of permissible solutions may be in the tens of millions. Once this list of all feasible solutions that satisfy the prerequisite and time-clash constraints is generated, the second phase applies Integer Linear Programming (ILP) techniques to allocate students to these timetables. Consideration is given to the selection of suitable ILP algorithms that scale well with the high dimensionality of the problem. An initial version has been applied to a timetabling problem in the Royal Australian Navy helicopter aircrew training program. The results of this application are compared, in terms of computational complexity, to an exhaustive best practice backtracking algorithm, and the quality of this solution compared favourably to standard meta-heuristic approaches such as Tabu Search and Simulated Annealing.

3 - Modeling the Royal Canadian Air Force (RCAF) air technician occupation
René Séguin

The air technician occupation is a highly specialized trade in the RCAF with hundreds of qualifications and authorizations required to maintain even just one single type of airplane. Personnel do attend standard classroom training courses but the large majority of their training is acquired on the job through a mentoring system where they gradually achieve higher levels of proficiency which eventually culminates in the authority to release a plane for flight operations. Modelling and simulating such a system presents many challenges. For instance, moving up in the hierarchy of skill levels is partly qualitative and is also influenced by the need for the pyramidal structure to be maintained when people at higher echelons retired (promotion when ready vs. when needed). There is also a chicken-and-egg element: technicians are required to maintain planes for flying missions but planes need to be flown for technicians to have work to do to acquire their skills. Finally, such a training/maintenance system needs to achieve a balance between time allocated to repairing aircraft, learning, mentoring and supervising. This implies having an adequate number of people at each level otherwise one or several aspects of the system will suffer with undesirable cascading and compounding effects on quality of personnel. This talk will present a simulation model that has been developed to study the occupation and the challenges that were encountered. Sample results will be discussed.

■ MB-31

Monday, 10:30-12:00 - 304B

Pollution management and environmental education

Stream: Energy economics, environmental management and multicriteria decision making
Invited session

Chair: *Martin Smid*
Chair: *Efsun Kürüm*

1 - Optimal dynamic emission covering
Martin Smid

The topic of our presentation is optimal emission covering by a risk averse CO2 producer, maximizing the Mean-CVaR criterion. The planning horizon is 2020, the decision period is one year. The emissions may be covered by a combination of the EUA and CER (spot) allowances and their futures with various maturities. We formulate a corresponding multistage decision problem which we solve by the SDDP algorithm implemented in C++. We demonstrate that the problem is efficiently solvable under a reasonable number of scenarios and that the optimization of emission covering reduces risk significantly in comparison with naive strategies.

2 - A performance based MCDM framework for the management of environmental pollution in major cities
H. Ziya Ulukan, Sigrid de Mendonca Andersen, Emre Demircioglu

Environmental pollution due to the air, water, soil pollution and many other factors is one of the most important problems of the contemporary world. These sources of pollution don't simply have a negative impact on the natural world, but they can have a measurable effect on the health of human beings as well. Pollution having a negative impact on the living environment is triggered by urbanization in metropolitan areas where the major cities possess the sharpest decline in livability. The aim of this paper is to propose an environmental decision support methodology based on an integrated Multi Criteria Decision Making approach in the context of major cities pollution. Among the most industrialized cities in Turkey, we seek to reveal less-polluted livable city. A hybrid method enables us to solve this trending environmental problem. In order to define the criteria list for the proposed problem, an expert group composed by the members of different national and municipal departments was selected. Once the criteria list was defined, it has been possible to obtain their coefficients of importance through the AHP methodology. Then, the TOPSIS method is applied as an outranking methodology to obtain a ranking of alternatives. Finally, we obtained most polluted and least polluted cities depending on the pollutants factors under consideration. We concluded this work by evaluating the performance of the approach for ranking cities based on their environmental pollution potential .

3 - Robust optimization under decision-dependent uncertainty sets
David Pozo

We address a problem where decisions have to be optimized given that the future is uncertain and the optimization decisions influence on the uncertain parameters. Standard approaches that represents unknown parameters, such as probability distributions or uncertainty sets, are in general, estimated with observed data, i.e., independent of the optimization decisions. We present a decision-support tool based on Robust Optimization under Endogenous Uncertainties mathematical framework. We apply this framework to the transmission capacity expansion planning problem in power systems. The objective is to minimize the total cost of new transmission assets and future operational cost considering uncertain renewable investments and physic laws, such as power flow constrains or generation limits. Location, size and technology of new renewable generation investments are decided by private investors and dependent, among others, on the locational nodal prices. Locational nodal prices depend on new transmission capacity and new generation investments. Thus, the endogenous uncertainty set of new renewable generation is dependent on transmission expansion decisions. The practical applicability of the proposed methodology is confirmed by numerical testing on several benchmarks. It is also compared with traditional frameworks dealing with uncertainty.

Monday, 13:30-14:30

■ MC-03

Monday, 13:30-14:30 - 200AB

Plenary speaker: Alvin Roth

Stream: Plenary sessions
Invited session
Chair: *Michael Trick*

1 - Marketplace design
Alvin Roth

Monday, 15:00-16:30

■ MD-01

Monday, 15:00-16:30 - 307B

Optimization for data science

Stream: European working group: Data science meets optimization
Invited session
Chair: *Andrew J. Parkes*
Chair: *Ender Özcan*

1 - Progress in analysis of the space of heuristics
Andrew J. Parkes, Asghar Neema Mohammad Beglou, Andrew Burnett

Many heuristic or metaheuristics algorithms, for solving combinatorial optimisation problems, have at their core a short decision procedure. The procedure encodes some choice of heuristic that is used in order to make help create, or improve, a solution. The performance of such heuristics is key to the overall algorithm; however, generally they are created by hand. We report on two methods towards automating the creation of such heuristics. Firstly, a study of "walkSAT" methods to solve propositional satisfiability, and in which we give results on the landscape of the space of heuristics, Secondly, a study of fine-grained parameter-based heuristics for online bin-packing. For both, we study the potential for machine learning to recognise the features of good heuristics.

2 - A schedule selection method for the proactive and reactive scheduling problem
Morteza Davari, Patrick De Causmaecker

In a previous work, we Modeled an integrated proactive and reactive scheduling problem as four different Markov decision processes (MDPs). The objective of this problem is to minimize the expected value of a combined cost which includes a baseline schedule cost as well as costs of a series of reactions. Each of these models (MDPs) takes a set of schedules as the input and outputs a PR-policy. A PR-policy is described by a set of decision rules that dictate certain transitions among schedules. The complication is that, because of computational reasons, the size of the input set of schedules must be very small (at most 2000 schedules), and therefore the quality of such a set directly influences the quality of the output PR-policy (note that there exists billions if not an infinite number of possible schedules). Thus, the main objective of this research is to wisely generate an input set of schedules such that the quality of the associated output PR-policy is reasonably high. To achieve this objective, we generate a very large number of schedules and map them to a huge multi-dimensional network where the nodes represent schedules and edges advocate connectivity between these schedules. Using clustering and data analysis on the network we heuristically select small sets of schedules with the objective of maximizing both diversity and total connectivity. In terms of the quality of the output PR-policies, initial experiments suggest promising results.

3 - Orienteering on a continuous surface
Joao Pedro Pedroso, Ke Zhang, Alpar Vajk Kramer

This paper describes a problem arising in sea exploration where the aim is to decide the schedule of a trip of a ship for collecting information about the resources (e.g., composition in certain materials) of the seafloor, here represented as a given bounded surface. For the sake of simplicity, we consider that the actual resource level at any location in the surface can be conveyed by a real number. This value is unknown, except for a limited number of locations. Optimal trip planning involves three subproblems, each corresponding to a different phase on the process. This first is assessment, which consists of the following: given a finite set of locations for which the contents are known, build and indicator function that associates to each location the "attractiveness" for exploring it. The second subproblem is planning, i.e., deciding on the position of a certain number of locations to probe in the next trip so as to maximize the overall informational reward. The third subproblem, estimation, is related to the final aim of the problem, which is to have an evaluation of the resource level available at any point of the surface, at the end of the trip. The first and the third subproblems are strongly related and we use Gaussian processes for this purpose.

4 - Knowledge representation and optimization
Tu San Pham, Patrick De Causmaecker

The number of combinatorial optimization problems arising from practical applications is rising dramatically in the last decade. Along with it is a wide variety of solving mechanisms, including Mathematical Programming, Constraint Programming (CP), Metaheuristics, Satisfiability checking of propositional logic (SAT), etc. Regardless of the mechanism used, solving a combinatorial problem is a difficult task which requires expert knowledge of the solving method. However, the number of optimization problems is outnumbering the number of solving experts. That is the motivation for a recent trend which separates the modeling phase and the solving phase - which is the main nature of Knowledge Base Systems (KBSs). In an ideal system, users can specify the problems' knowledge using a high-level language and let the solving mechanism handled by the underlying solvers. The solving mechanisms of such systems are mostly exact approaches like CP or SAT which have difficulties solving real world problems with large instances. In the field of optimization, heuristics and metaheuristics have shown their ability to deal with large instances. Therefore, integrating heuristics and metaheuristics to KBSs is presently receiving a lot of attention. In this work, we aim to design an input language to allow users to specify local search characteristics such as moves, heuristics, stop condition, delta-evaluation, hereby improving the solver's performance.

■ MD-02

Monday, 15:00-16:30 - 308B

Applying data analytics

Stream: Data science and analytics (contributed)
Contributed session
Chair: *A. D. Amar*

1 - Using the logical analysis of data to roads' clustering based on performance
Soumaya Yacout, Ahmed Elsheikh, Mohamed-Salah Ouali

This presentation describes the use of a machine learning and pattern recognition approach called Logical Analysis of data (LAD), to study the aging process of some roads in the province of Quebec. LAD detects structural information about data-sets. The key and unique feature of LAD is the discovery of knowledge from observations, in the form of interpretable hidden patterns that are capable of distinguishing and characterizing groups of observations of the same class of performance, from other classes. The roads' performance is measured by several performance' indices, and the observations are described by vectors of indicators which represent some controlled and some uncontrolled characteristics of each segment of road. The generation of patterns with LAD entails the solution of Mixed Integer Linear Programming problem, in which the objective is to find the patterns that cover the largest number of observations in each class, while the constraints impose the conditions that these patterns should not cover any observation from another class. In its simplest form, this is a set covering problem. The results shows that LAD finds interpretable patterns, which are very useful in characterizing the roads' performance, and thus in guiding the decision making process. Based on these patterns, families of roads were identified, and valuable information about the data collection process and the maintenance process were gained.

2 - Back to the future: Google deep mind's AlphaGo & Monte Carlo tree search
Michael Fu

In March of 2016 in Seoul, Korea, Google DeepMind's AlphaGo, a computer Go-playing program, defeated the reigning human world champion Go player, 4-1, a feat far more impressive than previous victories by computer programs in chess (Deep Blue) and Jeopardy (Watson). The main engine behind the program combines machine learning approaches with a technique called Monte Carlo tree search, a term coined by Rémi Coulom in his 2006 paper. Current versions of Monte Carlo tree search used in Go-playing algorithms are based on a version developed for games called UCT (Upper Confidence Bound 1 applied to trees), proposed by Kocsis and Szepesvári (2006), which addresses the well-known exploration-exploitation tradeoff that arises in multi-armed bandit problems by using upper confidence bounds (UCBs), a concept introduced to the machine learning community by Auer, Cesa-Bianchi, and Fischer (2002). We review the main ideas behind UCBs and UCT and show how UCT traces its roots back to the adaptive multi-stage sampling algorithm for estimating the value function in finite-horizon Markov decision processes (MDPs) in a paper published in Operations Research by Chang, Fu, Hu, and Marcus (2005), which was the first to use UCBs for Monte Carlo simulation-based solution of MDPs.

3 - Applying OR/Analytics to skiing: Whistler-Blackcomb's mega day challenge
John Lyons, Peter Bell, Mehmet Begen

Whistler-Blackcomb is North America's largest alpine ski resort. It implemented in Dec 2015 a system of radio-frequency identification (RFID) lift passes and sensor-gates across its network of 24 lift systems. The ability to track skiers forms the basis of a marketing web portal called 'WB+', through which skiers can view personal statistics, 'leader-boards' and related news and interest stories. Some describe it as a 'gamification' of skiing. A particular challenge called 'Mega Day' requires a skier to ride every lift on both Whistler and Blackcomb mountains in a single day, achieved in fewer than 0.05% skier-days since implementation. It demands a well-planned and executed route, subject to varying time windows. It shares features with various routing problems, but includes several unique ones. We modeled it as an MIP, using real data from Whistler-Blackcomb. While the optimal solution is somewhat dependent on individual skier characteristics, our model construction, experimentation and analysis of historical data provided a number of valuable insights to the WB+ team, and in turn a novel and interesting context to discuss route optimization concepts and methods.

4 - Real time weighted-dynamic time warping and exponential penalty
Inseok Lee, Jun-Geol Baek

To reduce manufacturing cycle time and production costs, fault detection is highly important. Traditional method, such as Statistical Process Control (SPC) and Partial Least Square (PLS) are used. However, in the manufacturing process, the difference of the process time hinders the comparing between the signals. Even if the comparison is possible, the performance of the classification varies depending on the classification boundary or threshold. To improve the problem Dynamic Time Warping and Exponential Penalty (DTWEP) is suggested. Unfortunately, DTWEP could not use as the real time detection method and the method's statistic is not reasonable. In this paper, we propose the real time fault detection method using Weighted-Dynamic Time Warping and Exponential Penalty (W-DTWEP). This method will provide the real time detection and more reasonable integrated statistic.

■ MD-03

Monday, 15:00-16:30 - 200AB

Keynote speaker: John Birge

Stream: Keynote sessions
Keynote session
Chair: Nelson Maculan

1 - Stochastic optimization with particles and Markov chains

John Birge

Many decision problems can be modeled as stochastic dynamic systems, which typically have state spaces that suffer from the curse of dimensionality and grow exponentially in both time and dimension. Even building simulations of these systems can be problematic in the presence of complex dynamics that depends on both previous actions and realizations of uncertain outcomes. This talk will describe computational approaches that maintain a fixed number of samples or particles in each period to counter the curse of dimensionality. The methods' convergence depends on the stationary distribution of a Markov chain defined over states and actions. These properties and comparisons with other approaches such as approximate dynamic programming will also be discussed.

■ MD-05

Monday, 15:00-16:30 - 203

Multiple classifier systems and applications

Stream: Multiple classifier systems and applications
Invited session
Chair: Anteneh Ayanso

1 - Supervised learning of predictive cadres

Alexander New, Kristin Bennett

We consider supervised regression problems in which the population under study may be softly partitioned into a set of cadres. The cadres create clusters of observations based on only a few features. Within these cadres, the behavior of the target variable is more simply modeled than it is on the population as a whole. We introduce a discriminative model for a population that, when trained on a set of observations, simultaneously learns cadre assignment and target prediction rules. Our formulation allows sparse priors to be put on the model parameters. These priors allows for independent feature selection processes to be performed during both the cadre assignment and target prediction processes, which results in simple and interpretable ensemble models. A block coordinate descent algorithm for parameter learning is developed. We present simulated results showing that, under certain conditions, our method significantly exceeds the performance of simpler methods that learn clustering and target prediction rules separately. Further experimental results show that our method is competitive with powerful nonlinear models such as regression forests. Applied to cheminformatics, our model accurately predicts polymer glass transition temperatures. It identifies chemically meaningful cadres, each with interpretable models. Future work includes learning analytically distinct patient cohorts in electronic healthcare records analysis and expanding the model to classification tasks.

2 - Learning from imbalanced big behaviour data

Jellis Vanhoeyveld, David Martens

Recent years have witnessed a growing interest in the imbalanced learning issue. While a plethora of techniques have been investigated on traditional low-dimensional data, little is known on the effect thereof on behaviour data. This kind of data reflects fine-grained behaviours of individuals or organisations, such as users visiting certain websites or making transactions with specific merchants, and is characterized by sparseness and very large dimensions. In this article, we investigate the effects of over-and undersampling, cost-sensitive learning and boosting techniques on the problem of learning from imbalanced behaviour data. This setup occurs in vital application areas such as fraud detection and predictive policing. Linear SVMs are used and AUC-performances are reported. Oversampling techniques show a good overall performance and do not seem to suffer from overfitting as traditional studies report. A variety of undersampling techniques are investigated and show the performance degrading effect of instances showing odd behaviour. Furthermore, the boosting process indicates that the regularization parameter in the SVM formulation acts as a weakness indicator and that a combination of weak learners can often achieve better generalization than a single strong learner. Finally, the EasyEnsemble technique is presented as the superior method in terms of AUC-performance and timings. We conduct statistical hypothesis tests in comparing each of the aforementioned techniques.

3 - Consensus similarity graph based on proximity relations

Tulin Inkaya

Ensemble approaches are promising methods for improving the accuracy, robustness and stability in clustering and classification problems. These approaches generate a set of solutions for the same data set, and aggregate them into a single solution. In this study, we apply ensemble approaches for similarity graph construction. A similarity graph represents the local characteristics of a data set. It is used as an input to various clustering methods including spectral clustering and hierarchical clustering. The proposed approach first constructs multiple similarity graphs based on proximity relations among the data points. Proximity graphs such as minimum spanning tree, relative neighborhood graph, Gabriel graph and Delaunay triangulation are used for this purpose. Then, the results of these proximity graphs are combined. The resulting similarity graph is called consensus similarity graph. The experimental analysis with synthetic and real data sets demonstrates the effectiveness of the proposed approach. Also, the robustness and stability of the consensus similarity graph are elaborated.

4 - Machine learning-based multi-criteria inventory classification

Anteneh Ayanso, Reena Yoogalingam

The ABC inventory classification system is the traditional method used to maintain efficient control over the large numbers of items firms carry in inventory. This classification system is based on the Pareto principle and commonly uses a single criterion, typically annual dollar usage, to determine groupings of the items. Category A items or high dollar usage items are few in number and account for 10-20% of inventory items and thus require tight inventory controls. Category B items are medium dollar items requiring regular control mechanisms. Approximately 30% of items fall into this category. Category C items are low dollar use items which are large in quantity, approximately 60-80%, and require minimal inventory control. While this approach is simple, it works in cases where all items are homogeneous and differ in terms of this criterion. In many cases, the items held in inventory are not homogeneous and may differ in terms of other criteria such as lead time and criticality. In this paper, we use decision tree-based and classification-based association rule mining techniques for multi-dimensional ranking of items. We illustrate the effectiveness of the technique using publicly available data in the literature and propose a general framework for its application in practice.

■ MD-06

Monday, 15:00-16:30 - 204A

CORS student paper competition (undergraduate)

Stream: CORS student paper competitions
Invited session
Chair: *Mehmet Begen*

1 - CORS Student paper competition (Undergraduate)
Mehmet Begen

Presentations of finalists for the CORS student paper competition (undergraduate category).

■ MD-07

Monday, 15:00-16:30 - 204B

Inverse optimization

Stream: Inverse optimization
Invited session
Chair: *Daria Terekhov*

1 - Solution methods for generalized inverse optimization
Rafid Mahmood, Timothy Chan

Inverse optimization is a model fitting technique that uses observed decisions to impute the cost function of an unknown optimization problem. In application however, practitioners often create customized inverse optimization methods to solve their specific problem. Noting that the different methods share very similar characteristics, a previous work introduced a generalized inverse optimization (GIO) formulation for imputing the cost function of a linear program. The work proved that GIO could be specialized to application-specific variants and proposed a solution method for a single feasible observed decision. In this work, we first extend the formulation of GIO for linear programs to the case of multiple observed points and propose a general solution method to impute the cost function given any set of observed decisions. We show several special cases where this method simplifies significantly and the solution can be analytically obtained, as well as analytic bounds. In the sequel, we consider the problem of formulating GIO for convex optimization problems and show how the principles of the linear programming approach can be extended to construct an algorithm to solve this extension.

2 - A non-parametric inverse optimization framework for identifying risk measures
Jonathan Li

In this work, we present a novel inverse optimization framework that imputes a risk measure based on the information of observable made decisions and an initial estimate of the risk measure. Unlike classical inverse optimization, no parametric assumption is made about the risk measure. We show that the inverse problems can always be reduced to finite-dimensional convex programs and are polynomially solvable if the forward problems are so. The framework can be applied for a wide range of stochastic programs involving the use of risk measures.

3 - Robust inverse optimization
Daria Terekhov, Taewoo Lee, Houra Mahmoudzadeh, Kimia Ghobadi

Given observed data of a decision maker's uncertain behavior, we develop a robust inverse optimization framework that infers the decision maker's objective function (e.g., cost or utility function) while protecting against the worst misspecification of the decision maker's behavior. To do so, we assume an uncertainty set around a given observation which may or may not intersect the feasible region. We derive cost vectors that are robust with respect to the uncertainty set, characterize the corresponding optimal solutions, and propose tractable solution methods. Our robust inverse framework generalizes previous single-observation inverse models as the uncertainty set can be reduced to a singleton. We show the application of our proposed models in the context of inferring the preferences of a person following a regimented diet.

■ MD-08

Monday, 15:00-16:30 - 205A

City logistics: Routing research and applications

Stream: City logistics and freight demand modeling
Invited session
Chair: *Eiichi Taniguchi*
Chair: *Hugo Yoshizaki*

1 - Collaborative freight systems
Alysson Costa, Russell Thompson, Ronny Kutadinata

Distribution systems in metropolitan regions are typically characterised by suppliers operating their own vehicle fleets, distributing only their goods to their customers on a regular basis. In sectors where there are multiple suppliers servicing common customers, there is an opportunity to develop collaborative systems combine distribution networks to reduce the distance travelled by delivery vehicles. This can result in substantial savings in transport operating costs as well as environmental costs. With the collaborative system, one supplier is selected for the location to exchange goods between suppliers where goods with destinations near other suppliers are transferred to these suppliers. In the first level, the model decides the hub location, the transfers between the suppliers and the hubs and the consequent inventory levels at each supplier. The inventory level acts as linking variables between this first level and the distribution network, which decides on the routes of the suppliers. This talk presents a model for designing supplier exchange networks as well as routes from suppliers to customers. Sets of time periods (days) are specified when exchanges between suppliers can occur as well as when distribution to customers can occur. Constraints are defined for handling inventory levels of products at suppliers after supplier exchanges, vehicle capacities as well as demand and supply conditions.

2 - Container loading and cross-docking in city logistics
Pedro Castellucci, Franklina Toledo, Alysson Costa, Russell Thompson

Reducing unused space in freight transportation can increase logistic operations efficiency. Particularly in urban scenarios, this translates in less traffic, accidents, noise and air pollution. This fact has motivated decades of research on container loading problems. However, the literature has mostly failed to contemplate the fact that container loading process is part of a broader dynamic logistic operation. Motivated by a multi-echelon urban distribution scenario, we propose optimization models for container loading problems that do not assume all boxes are available at the beginning of the loading process. We also propose an effective decomposition approach in which the sub-problems are "classic" container loading problems. Finally, we present a quantitative analysis of recent papers on container loading problem, which might give researchers a landscape of current best solution approaches and contemplated characteristics.

3 - Evaluating off-hours deliveries for time and capacity constrained urban distribution systems with a continuous approximation model

Hugo Yoshizaki, *Claudio B. Cunha*

We present a method based on Daganzo's continuous approximation model for trip lengths to calculate operational and cost indicators in order to evaluate the impact of off-hour deliveries (OHD) from a shipper/carrier perspective. Using data from the successful OHD pilot project in São Paulo, Brazil, different customer densities, drop sizes, and distribution centre distances were employed. From these results, two distinctive behaviors emerged in what we categorize as two different types of last-mile distribution systems, time and capacity-constrained. Time-constrained distribution systems encompass cases where average drop sizes are much smaller than vehicle capacity, thus total number of deliveries in a single tour is limited by driver working hours and not by vehicle capacity. Capacity-constrained distribution systems have larger drop sizes, and the number of deliveries is limited by vehicle capacity. Results show that, for time-constrained distribution systems, OHD in any proportion are always advantageous from a cost standpoint, as corroborated by literature. But, for capacity-constrained distribution systems, best results occur when about 45% of deliveries are shifted to off-hours. This allows a new opportunity to be explored, which is related to freight vehicles performing two trips at night in this last case. One important finding is that differentiated deployment strategies should be employed for each type of last-mile distribution systems.

■ MD-09

Monday, 15:00-16:30 - 205B

2017 IFORS prize for OR in development 1

Stream: 2017 IFORS prize for OR in development
Invited session

Chair: *Mikael Rönnqvist*
Chair: *Ke Liu*
Chair: *Richard Larson*
Chair: *Mario Guajardo*
Chair: *Víctor Parada*
Chair: *Jan van Vuuren*
Chair: *Guillermo Durán*
Chair: *Roman Slowinski*
Chair: *Peter Bell*
Chair: *Sue Merchant*

1 - Optimization models and algorithms for fingerprint recognition and its applications in AFIS of China

Tiande Guo, *Congying Han*, *Tong Zhao*, *Yong A*, *Chaochao Bai*, *Siqi Tang*, *Min Wu*

A general optimization model of Automatic Fingerprint Identification System (AFIS) is proposed in our presentation. For solving the general model, a serial of optimization models and algorithms are established and designed combining with the real condition of China, including the modules of feature extraction and minutiae matching in AFIS. AFIS has become increasingly more difficult than ever in China: the fingerprint database is very large, the collection qualities of the fingerprint images are very poor in some regions, comparison time is very long, and large database attenuation becomes seriously. To the low-quality fingerprint images and the large database, we proposed a global optimization model for orientation field computation, a variable dimension optimization model for singular point detection, and a bipartite graph optimization model for minutiae matching. According to the characteristics of fingerprint image, novel algorithms are designed for these three models. These algorithms were embedded in our AFIS, which has been successfully applied to many provinces (cities) in China, which has played an important role in cracking and preventing all kinds of criminal cases.

2 - Performance assessment and definition of improvement paths towards the double bottom-line of microfinance institutions: An application to the MC' network in Cameroon

Isabelle Piot-Lepetit, *Nzongang Joseph*

An assessment of the financial and social performance of village banks of the MC2 (Mutuelles Communautaires de Croissance) network in Cameroon is implemented to provide guidance to both top and local managers, to help them in their decision-making process, and to achieve their social mission in a sustainable manner. Indeed, microfinance institutions face a double bottom-line (financial sustainability and outreach to the poor). Managing both objectives without trade-off is not an easy task and assessing their performance in both dimensions is of real importance for ensuring a sustainable activity and an impact of microfinance institutions. To support decision-making towards performance, this paper develops an analytic framework in three phases. First, Data Envelopment Analysis (DEA) models are implemented for measuring efficiency, identifying best practices, and setting benchmarking goals to less efficient MFIs. Then, a DEA operating frontier (DEA-OF) approach is designed to identify improvement paths, setting short-term goals towards their long-term target. Finally, DEA results are translated into indicators daily used by managers of village banks to provide them effective guidance in developing actions in accordance with their mission as well as possibilities to learn from other village banks of the MC' network.

■ MD-10

Monday, 15:00-16:30 - 205C

Production and warehousing

Stream: Production management, supply chain management (contributed)
Contributed session

Chair: *Yves R. Sagaert*

1 - A decade of academic research on warehouse order picking: Trends and challenges

Babiche Aerts, *Trijntje Cornelissens*, *Kenneth Sörensen*, *Christof Defryn*

Warehouses play a key role in supply chain operations. Due to the recent trends in, e.g., e-commerce, the warehouse operational performance is exposed to new challenges such as the need for faster and reliable delivery of small orders. Order picking, defined as the process of retrieving stock keeping units from inventory to fulfil a specific customer request, is seen as the most labor-intensive activity in a warehouse and is therefore considered to be an interesting area of improvement in order to deal with the aforementioned challenges. A literature review by de Koster et al. offers an overview of order picking methods documented in academic literature up until 2007. We take this publication as a starting point and review developments in order picking systems that have been researched in the past ten years. The aim of our presentation is to give an overview of the current state of the art models and algorithms and to identify trends and promising research directions in the field of order picking.

2 - An integrated cluster-based storage policy

Masoud Mirzaei, *Nima Zaerpour*, *René de Koster*

Storage systems are important nodes in the supply chain as they allow matching supply with customer demand and achieving economies of scale in transport. One of the most labor intensive operations in the storage systems is order picking. Several storage policies are used to obtain better performance of the system in term of time and cost. In the random storage policy products are randomly allocated to the available space. Full Turnover-Based (FTB) policy ranks all products based on COI (Cube per Order Index) and allocate more popular products closer to the I/O point. Class-based storage (ABC) policy classifies products in A, B and C classes based on product popularity and allocates them to the respective zone, with the popular classes closer to the I/O point. In practice, orders can consist of more than one product line and some products are ordered together more often. By identifying the affinity between products, it is possible to cluster them based on the demand, and allocate the clusters to the storage locations such that the order picking time is reduced. We propose an integrated cluster allocation storage (ICAS) policy to improve the order picking time. Preliminary results show significant savings can be achieved by using the ICAS policy as compared to existing FTB and ABC policies. The model has limited benefits when orders do not consist of multiple products or there is a little affinity between products.

3 - Setting optimal planned leadtimes for activities in a production network
Sjors Jansen, Zumbul Atan, Ton de Kok, Ivo Adan

The production of high value, customer specific products, such as aircrafts, consists of a large number of activities. Since each activity has precedence relations, we model the production network as a Directed Acyclic Graph (DAG), where each node represents an activity. Each node has a stochastic leadtime. We incur holding costs from the moment an activity is started, until the delivery to the customer. If the product is not finished at the due date, penalty costs are incurred. Our objective is to minimize the total expected costs, by determining the optimal planned start time for each activity. For the unconstrained problem, we show that for each node, a Newsvendor fractile can be derived, which denotes the probability that under the optimal solution, a specific activity in the network causes the final product to be finished late. To determine the planned start times, simulation based optimization is used. We show that our method gives near optimal results in a short amount of time for networks of significant size. Furthermore, we will show a few extensions of the problem. As an extension, we include constraints for certain resources which might be only available during certain time windows. Also, we extend the model by adding the possibility of shortening the expected duration of an activity (at higher costs) in order to meet the due date.

4 - Improving tactical sales forecasting for supply chain management with global macroeconomic big data
Yves R. Sagaert, Nikolaos Kourentzes, El-Houssaine Aghezzaf, Bram Desmet

Tactical forecasting up to 12 months ahead is an important input in the Sales & Operations Plan (S&OP) that supports planning for inventory, scheduling production, and raw material purchase, amongst other functions. Traditional forecasting models extrapolate past univariate information, but they cannot anticipate on macroeconomic events, such as steep increases or declines in national economic activity. These statistical models are often adjusted with managerial insights, but this method is known to suffer from various biases, is expensive and not scalable. This research evaluates multiple approaches to improve tactical sales forecasting using macro-economic big data as leading indicators. The proposed statistical framework automatically selects both the type of leading indicators and the appropriate lead of each of the selected indicators. Purely statistical models are evaluated against judgemental aided models, where management input is used to pre-filter potential leading indicators. The proposed framework improves on forecasting accuracy over industry benchmarks, identifying the key leading indicators. This enables industry companies to gain insight in obvious and hidden leading indicators of their sales, providing more information to S&OP meetings.

■ MD-11

Monday, 15:00-16:30 - 206A

Transport demand and network modeling

Stream: Traffic flow theory and control
Invited session
Chair: Emma Frejinger

1 - Prediction of multimodal route choices in a dynamic public transport network
Maëlle Zimmermann, Kay Axhausen, Emma Frejinger

In this study we model the route choice behavior of users in multimodal public transport networks. We show how the link-based Recursive Logit model (parametric Markov decision process), which can be consistently estimated without requiring any choice sets of paths, may be adapted to this context. We use a real network in the city of Zürich and we estimate the model parameters using observed route choices from that network. This work addresses several challenges that occur in a dynamic multimodal setting. Given a public transport network and timetable information, we derive a time-space network in which each node is a (location,time) pair linked by transit, transfer or waiting arcs. The resulting network for Zürich is composed of over a million arcs. We propose different ways for computing the value functions (dynamic programming problem) in this network. We also propose to reduce the size of the state space by decomposing the network into static layers for high frequency services and time-space layers for scheduled services.

2 - Real-time toll optimization based on prediction
Bilge Atasoy, Ravi Seshadri, Moshe Ben-Akiva

We present a real-time toll optimization framework where the toll optimization is integrated with a mesoscopic traffic simulator, DynaMIT, so that the tolls are optimized based on predicted traffic conditions. The distinction of the work is the adaptive nature of the rolling-horizon toll optimization where the tolls can be changed as frequent as every 5 minutes based on the predicted travel times for the near future (e.g., next 1 hour). As DynaMIT includes behavioral models for route choice, the tolling decision is based on travelers' reaction to toll and travel time among other variables. Revenue maximization and travel time minimization formulations are developed to represent the viewpoint of transport operators and the travelers, respectively. For the solution of the optimization problem we work with different methods including genetic algorithm and intelligent search heuristics. We test the idea on case studies in Singapore and Texas that shows the potential in reducing network-wide travel times and increasing operator's revenue.

3 - Arc-based MILP reformulation of a traffic control bi-level program
Leonard Morin, Emma Frejinger, Bernard Gendron

In this talk, we focus on a traffic control application. It consists of a transportation network manager who wants to allocate resources to control traffic flow on arcs in a network. The network manager has to take into account that there are several classes of users including those who have objectives that are antagonistic to his own. We present a bi-level programming formulation of this problem where an arc-based logit model predicts the path choices. We then reformulate it as a mixed integer linear program with a sample average approximation of the logit model over the scenarios sampled from the distribution of the latter.

4 - On the nested fixed point algorithm for recursive route choice models
Emma Frejinger, Tien Mai

This talk concerns the use of the nested fixed point (NFXP) algorithm (Rust 1987) for estimating recursive route choice models, which are parametric Markov decision processes without discount factor. The algorithm consists of an outer iterative nonlinear optimization algorithm for searching over the parameter space and an inner algorithm for computing the fixed point solution. The inner algorithm is typically based on a simple value iteration method. In this work, we establish conditions for the existence of a fixed point solution, and for the convergence of the value iteration method. We show that in the case of the recursive logit model (Fosgerau et al., 2013) the value iteration method converges to a unique solution, but it is not the case for the nested recursive model (Mai et al., 2016). Thus, for the latter we propose to use a trust region algorithm to solve the value functions. We provide results using real data and show that the trust region algorithm outperforms the classical value iteration.

■ MD-13
Monday, 15:00-16:30 - 207

Vehicle scheduling

Stream: Scheduling problems in logistics
Invited session
Chair: Simon Emde

1 - Truck scheduling with workforce dependent processing times
Giorgi Tadumadze, Nils Boysen, Simon Emde, Felix Weidinger

Truck scheduling coordinates the loading and unloading processes of trucks competing for the timely processing at some terminal, e.g., a cross dock or distribution center. Existing research invariably assumes that the (un-)loading times of trucks are fixed and deterministic. In the real-world, however, terminal managers have the additional flexibility to adapt the workforce for processing critical trucks. For instance, two instead of one worker can be applied to jointly unload the parcels reaching a terminal of the postal service industry onto a conveyor or an additional forklift can support the removal of pallets from a truck in a distribution center. Thus, workforce management influences the processing times of trucks and a simultaneous planning of both tasks seems advisable. This paper investigates the impact of a holistic planning approach on the performance. For two representative truck scheduling settings mixed-integer models integrating workforce planning are derived, solution procedures are presented and compared with alternative models assuming a fixed workforce. Our findings reveal that an integrated planning can considerably increase the performance of truck scheduling.

2 - A multiperiod auto-carrier transportation problem with probabilistic future demands
Christian Billing, Florian Jaehn, Thomas Wensing

In this study we investigate an auto-carrier transportation problem (ACTP) over multiple periods with probabilistic knowledge about future demands. The ACTP, a routing problem with special loading constraints, is a major topic in the automotive industry, as the delivery of produced cars can be quite costly. While locations of dealers that must be serviced are steady over the planning horizon, the requests for cars arrive dynamically and must be fulfilled until a given deadline. So, the decision about the set of customers to deliver must be made day by day without complete information about the future. However, we assume probabilities for incoming requests of all dealers and examine how this knowledge can be exploited to form suitable tours. Additionally, we focus on tours with a limited number of customers as too many stops are unpleasant, especially for the drivers of auto-carriers. We present some interesting theoretic results for special cases and use them in a heuristic approach.

3 - Scheduling electric vehicles for just-in-time in-house part feeding
Simon Emde, Hamid Abedinnia, Christoph Glock

Battery-operated electric vehicles are frequently used in in-plant logistics systems to feed parts from a central depot to workcells on the shopfloor. These vehicles, often so-called tow trains, make many milk-run trips during a typical day, with the delivery timetable depending on the production schedule. To operate such a milk-run delivery system efficiently, not only do the timetabled trips need to be assigned to vehicles, it is also important to take the limited battery capacity into consideration. Moreover, since most tow trains in use today are still operated by human drivers, fairness aspects with respect to the division of the workload also need to be considered. In this context, we tackle the following problem. Given a fixed schedule of milk-runs (round trips) to be performed during a planning horizon and a fleet of homogeneous electric vehicles stationed at a depot, which vehicle should set out on which milk-run and when should recharging breaks be scheduled, such that all runs can be completed with the minimum number of vehicles and all vehicles are about equally busy? We investigate the computational complexity of this problem and develop suitable heuristics, which are shown to solve instances of realistic size to near-optimality in a matter of a few minutes. We also offer some insight into how battery technology influences vehicle utilization.

■ MD-14
Monday, 15:00-16:30 - 305

Matching and dynamic markets

Stream: Algorithmic/computational game theory
Invited session
Chair: *Inbal Talgam Cohen*
Chair: Shai Vardi

1 - Dynamic matching in school choice: Efficient seat reallocation after late cancellations
Irene Lo, Itai Feigenbaum, Yash Kanoria, Jay Sethuraman

In many centralized school admission systems, a significant fraction of allocated seats are later vacated, for instance because students obtain better outside options. We consider the problem of reassigning these seats in a fair and efficient manner while also minimizing the movement of students between schools. Centralized admissions are typically conducted using the deferred acceptance (DA) algorithm, with a lottery used to break ties caused by indifferences in school priorities. The key idea we introduce is to reassign vacated seats using a suitable permutation of the first round lottery numbers. In particular, we show that a mechanism based on a simple reversal of the first-round lottery order performs well. In a model with no school priorities, we show that this "reverse lottery" mechanism is the best among all truthful mechanisms satisfying some natural efficiency and fairness properties. Empirical investigations based on data from NYC high school admissions suggest that our mechanism performs well even in the presence of school priorities.

2 - Near-optimal exploration-exploitation approaches for assortment selection
Vashist Avadhanula, Shipra Agrawal

We consider an online assortment optimization problem, where in every round, the retailer offers a K-cardinality subset (assortment) of N substitutable products to a consumer, and observes the response. We model consumer choice behavior using the widely used multinomial logit (MNL) model, and consider the retailer's problem of dynamically learning the model parameters, while optimizing cumulative revenues over the selling horizon T. Formulating this problem as a variant of the multi-armed bandit (MAB) problem, we present algorithms based on a) the principle of optimism in the face of uncertainty, and b) posterior sampling. A naive MAB formulation would treat each of the possible assortments as a distinct "arm", leading to regret bounds that are exponential in K. We show that by exploiting the specific characteristics of the MNL model, under a mild assumption, our algorithms achieve given regret bounds. These regret bounds are essentially the best possible. Our posterior sampling based algorithm also shows superior empirical performance to any existing approach. This talk is based on joint work with Vashist Avadhanula, Vineet Goyal, Assaf Zeevi.

3 - Spatial-temporal pricing for ridesharing platforms
Hongyao Ma, Fei Fang, David C. Parkes

Ridesharing systems match drivers and riders via priced trips, and employ dynamic surge pricing to balance supply and demand. When prices fail to be temporally or spatially smooth, drivers may prefer to decline matches or turning off their apps for some period of time, either waiting for higher prices or driving to another region. This leads to failure of individual rationality and inefficient outcomes. We study the welfare-optimal matching of drivers with riders (or otherwise tell the drivers where to go.) The goal is to compute anonymous, spatial-temporal trip-prices that ensure envy-freeness and straightforward participation of drivers. We obtain positive results under the assumption of complete information, impatient riders, and drivers who remain in the system past the end of the planning horizon. Ongoing work includes generalizing the model to bring in uncertainty and information asymmetry on future demand/supply, and studying driver collusion.

4 - Controlled dynamic fair division
Shai Vardi

In the single-resource dynamic fair division framework there is a homogeneous resource that is shared between agents dynamically arriving and departing over time. When n agents are present, there is only one truly "fair" allocation: each agent receives 1/n of the resource. Implementing this static solution in the dynamic world is notoriously impractical; it requires too many disruptions to existing allocations: for a new agent to get her fair share, all other agents must give up a small piece. A natural remedy is to restrict the number of allowed disruptions when a new agent arrives. We consider the following benchmark - the "fairness ratio" - the ratio of the minimal share to the ideal share (1/n when there are n agents in the system). We describe an algorithm whose input is a vector of allowed disruptions, where the k-th entry represents the number of disruptions allowed when k agents are present in the system (an entry can be zero), and whose output is sets of allocations. We show that this algorithm is optimal - it achieves the best possible fairness ratio - and show that the fairness ratio decays logarithmically with c, where c is the longest number of consecutive time steps in which we are not allowed any disruptions.

■ MD-15

Monday, 15:00-16:30 - 307A

Interior point methods 2

Stream: Continuous optimization (contributed)
Contributed session
Chair: Florian Potra

1 - A new preconditioner for a second order method for compressed sensing problems
Paula Kikuchi, Aurelio Oliveira

An efficient technique to acquire and reconstruct signals is called Compressive Sensing (CS). The theory about CS asserts that we can recover certain signals and images through few samples. This is possible because the signal of interest is sparse through a coherent and redundant dictionary, and the linear system matrix satisfies the Restricted Isometry Property (RIP) under reasonable assumptions. The problem consists in finding a solution with minimum 1-norm that satisfies an underdetermined linear system. The 1-norm is replaced by the pseudo-Huber function obtained by means of the dual formulation. The optimality conditions are written in their real and imaginary parts. An approach for solving this problem is the Primal-Dual Newton Conjugate Gradient method. Using the fact that, close to a solution, we can split the variables in two groups, those that have values far from zero, and those with values tending to zero; and that the matrices satisfy the RIP, an appropriate preconditioner is provided in the literature. This work consists in the application of a new preconditioner for this problem, achieving better results than the previous one. For this, we continue to exploit the features of the problem, as previously done. Once the preconditioner exploring these characteristics has been computed, we apply an incomplete Cholesky factorization on it, and use the factor found as the true preconditioner. Satisfactory preliminary computational results are presented.

2 - Interior point methods for sufficient horizontal LCP in a wide neighborhood of the central path with best known iteration complexity
Florian Potra

Three interior point methods for sufficient horizontal linear complementarity problems (HLCP) are presented: a large update path following algorithm, a first order corrector-predictor method, and a second order corrector-predictor method. All algorithms produce sequences of iterates in the wide neighborhood of the central path introduced by Ai and Zhang. The algorithms do not depend on the handicap of the problem, so that they can be used for any sufficient HLCP. Their iteration complexity is proportional to the square root of the dimension and the handicap of the problem, the best iteration complexity obtained so far by any interior point method for solving sufficient linear complementarity problems. The first order corrector-predictor method is Q-quadratically convergent for problem that have a strict complementarity solution. The second order corrector-predictor method is superlinearly convergent with Q order 1.5 for general problems, and with Q order 3 for problems that have a strict complementarity solution.

■ MD-17

Monday, 15:00-16:30 - 309A

Non-linear discrete optimization, facets, enumeration and linearization

Stream: Discrete optimization - Computational methods
Invited session
Chair: João Lauro Faco'

1 - Integer L-shaped algorithm and MISOCP for nonlinear network design problem
Emine Gundogdu, Sinan Gürel

We consider a deterministic nonlinear wireless local area network design problem in which power level selections and the allocation decisions are made simultaneously. The aim is to minimize the total power consumption at access points. Due to the structure of the problem and to handle nonlinearities occurred in the capacity constraints, we implement an Integer L-shaped algorithm, Branch and Benders cut approach and MISOCP reformulation for two versions of the problem. We conducted an extensive computational study to compare the performance of the algorithms. Computational study demonstrates that MISOCP gives smaller CPU time and solves more problems to optimum when the optimal number of access points required to satisfy the demand of user terminals is high in the optimal solution. To the best of our knowledge, this study is the first implementing Integer L-shaped algorithm and second order conic reformulation for this problem.

2 - Complex MINLP by the generalized-CGRASP method
João Lauro Faco', Ricardo Silva, Mauricio Resende

Complex decision support systems require the formulation of nonlinear models with a large number of variables, some of them discrete. Large-scale Mixed-Integer Nonlinear Programs (MINLP) are difficult to address by classical combinatorial relaxation techniques due to the curse of dimensionality phenomenon. The Generalized-CGRASP method - a hybrid GRASP/C-GRASP metaheuristic - avoids many combinatorial difficulties doing an a priori random search in a discrete set. The random search and local improvement phases of Generalized-CGRASP independently use a discrete and a continuous set. The linear or nonlinear constraints are incorporated in the objective function by quadratic penalty terms. Numerical solutions to MINLP instances are presented, and a complex planning problem - the scheduling of oil derivatives operations in ports, pipelines and refineries - is discussed.

3 - Linearization and quadratization techniques for multilinear 0-1 optimization problems
Elisabeth Rodriguez-Heck, Yves Crama

We are interested in the unconstrained minimization of multilinear polynomials in 0-1 variables. More precisely, we consider two different reformulation techniques to approach this problem: linearization and quadratization. Linearization is a classical approach, which was first introduced in the late fifties, that consists in defining first a linear reformulation of the objective function which is then optimized using integer linear programming techniques. Quadratization is a more recent approach that consists in first reformulating the objective function as a quadratic polynomial and then using quadratic binary optimization techniques. Quadratizations first appeared in the seventies, and have drawn much attention in recent years. Interestingly, much progress has been done in the field of computer vision, where quadratization techniques have resulted in great performance for very large optimization problems. We investigate reductions to the linear and the quadratic case as well as the quality of the bounds that they yield, both from the theoretical and from the computational point of view.

4 - Getting strong bounds for the crossdock door assignment problem using a Lagrangean relaxation of an RLT model having the 0-1 ILP
Jongwoo Park, Monique Guignard-Spielberg

The Generalized Quadratic Assignment Problem (GQAP) is an especially difficult quadratic nonconvex 0-1 optimization problem. It is nearly impossible to solve it within a reasonable amount of time without using carefully tuned methods. Lower bounds for minimization GQAPs are particularly difficult to obtain. We present an approach based on applying to an RLT (Reformulation Linearization Technique) model a Lagrangean relaxation with the 0-1 Integer Linearization Property (ILP), as proposed by Guignard (2006). We solve the Lagrangean relaxation with the Surrogate subgradient method proposed by Bragin, Luh, Yan, Yu and Stern (2014) to provide high quality lower bounds in relatively short computation times with a performance guarantee. There are two techniques in the numerical method that help us solve the problem in reasonable time. First, we solve a few subproblems to find surrogate directions (interleaved method). Second, we save feasible solutions and reuse them to update the Lagrangean multipliers. Computational results with the Crossdock Door Assignment Problem (CDAP), a special case of the GQAP, for instances of moderate sizes, open up possibilities for solving larger-size problems. We present extensive computational results for the CDAP and compare them with a dual ascent method for computing RLT1 and RLT2 bounds for the same instances (Hahn, 2017).

■ MD-18
Monday, 15:00-16:30 - 2101

Game theory and its applications

Stream: Game theory, discrete mathematics and their applications
Invited session
Chair: Ryusuke Hohzaki

1 - A security game with attrition on a network
Ryusuke Hohzaki

This report deals with a security game, in which multiple types of invaders/attackers invade a facility represented by a network to make the damage on the facility larger and several types of security/defender teams try to minimize the damage by intercepting them. A conflict between the invaders and the security occurs some attrition on both sides ruled by Lanchester's linear law. The security may randomize the usage of his types with an optimal deployment of guards and the invaders may take a randomized routing plan on the network after knowing a part of the security plan. We model the security game by Stackelberg games and solve them by linear programming and quadratic programming problems to investigate the best configuration of the security types to mitigate the damage caused by the invaders.

2 - A discrete fixed point theorem and an existence theorem of a pure-strategy equilibrium
Hidefumi Kawasaki

Fixed point theorems, such as Brouwer and Kakutani, play an important role to show the existence of an equilibrium for a strategic game. One gets a mixed-strategy equilibrium by applying a fixed point theorem to the best response (set-valued) mapping. If we apply a discrete fixed point theorem to the best response mapping, we will obtain a pure-strategy equilibrium. This talk aims to present a sufficient condition for a strategic game to have a pure-strategy equilibrium. We use a discrete fixed point theorem base on Brouwer's fixed point theorem. Our approach is as follows. (1) Let X be the product of bounded integer intervals. (2) Let f be a mapping from X into itself. (3) We construct a simplicial decomposition of the convex hull of X. (4) Let g be a piecewise linear extension of f. (5) We apply Brouwer's fixed point theorem to g, and get a fixed point of g. (6) We impose an assumption, called direction preserving condition, to guarantee the fixed point be an integer point. We characterize the direction preserving condition for the best response mapping and for any simplicial decomposition.

3 - A two-person timing game with a general valued function and a constant discount rate
Hitoshi Hohjo

This paper explores a two-person nonzero-sum timing game with trade-off relation of the price function between increasing in time and decreasing by discount. There are two players competing on a market and they plan their timing to put their products. The objective of each player is to put his product at the optimal time maximizing his expected payoff, considering the opponent's timing with each other. In a silent game, given a general valued function and a constant discount rate, we show an equilibrium point exists in a class of mixed strategies.

4 - An approach to solve interval-valued generalized solidarity values of cooperative games under interval setting
Deng-Feng Li, Wei Fei

In some real management situations, payoffs (or values) of player coalitions in cooperative games are expressed with intervals. Such a kind of cooperative games is often called interval-valued cooperative games for short. There are some solutions such as the Shapley value which are proposed for the interval-valued cooperative games. However, the solidarity value, which has some remarkable features, is different from the Shapley value. Therefore, the main purpose of this paper is to study and develop an effective and efficient and a practical methodology for computing interval-valued cooperative games. In this methodology, defining the concept of an interval-valued generalized solidarity value for interval-valued cooperative games and adding some weaker coalition monotonicity-like conditions, we prove that the generalized solidarity values are monotonic and non-decreasing functions of player coalitions' payoffs. Hereby, the interval-valued generalized solidarity values can be directly and explicitly obtained via determining their lower and upper bounds through using the lower and upper bounds of the interval-valued coalitions' payoffs, respectively. The developed method does not use the Moore's interval subtraction and hereby can effectively avoid the issues resulted from it. Moreover, we discuss some important and useful desired properties of interval-valued generalized solidarity values.

■ MD-19
Monday, 15:00-16:30 - 2102AB

Business analytics 2

Stream: Business analytics
Invited session
Chair: Kristof Coussement
Chair: *Wouter Verbeke*
Chair: *Dries Benoit*

1 - Customer intelligence and analytics in the financial industry: A unifying customer lifetime value-based analytics framework
Sam Verboven, Wouter Verbeke

Most financial institutions employ a variety of metrics and analytical models to assess customer behavior in terms of acquisition, development, retention, risk, revenues, etc., across various products and services. These metrics and models provide insight and knowledge with regards to specific customer characteristics, but they typically do not allow to assess and manage a customer as a whole. The various operational analytical models are rarely brought together and linked in a single framework providing a full overview of a customer. In this paper we introduce and demonstrate the need, use, and advantages of such a comprehensive framework. We present a highly flexible, modular approach to linking and aggregating existing customer-level analytics models by adopting an extended Customer Lifetime Value metric adapted to the financial industry. Consequently, we show how this opens up new pathways to business intelligence and decision making by describing multiple practical applications.

2 - Leaf modeling: An application in customer churn prediction
Arno De Caigny, Kristof Coussement, Koen W. De Bock

An important part of CRM is customer churn prediction where one aims to predict whether or not a customer will leave the company. In previous customer churn research a lot of attention has been given to predictive accuracy that is typically evaluated using statistical methods or profit centric performance measures. On the other hand far less attention has been paid to other key aspects of churn prediction models like comprehensibility, justifiability, interpretability and scalability. Therefore a new data mining technique is presented, namely leaf modeling that scores well on all key aspects of churn prediction. The idea behind leaf modeling is that different models constructed on segments of the data rather than on the entire dataset lead to better predictive accuracy while maintaining the benefits of high comprehensibility and interpretability from the models constructed in the leaves. Leaf modeling consists of two stages: a segmentation phase and a prediction phase. In the first stage data segments are automatically and dynamically created using decision rules that consequently can be summarized in a tree like structure. In the second stage a model is created for every leaf of this tree. This approach is benchmarked against machine learning approaches, statistical approaches and other two-step approaches regarding the above mentioned key aspects of churn prediction models.

3 - Churn Prediction using hierarchical generative models
Wai Kit Tsang, Dries Benoit

Predicting customer churn creates opportunities to target customers with a marketing action or a promotion to prevent them from leaving. In this paper, a hierarchical generative approach will be applied in the context of churn prediction. The dependent variable and the covariates are modeled jointly conditioned on a deep latent structure, which resembles the hidden structure in neural networks. The conditional latent structure is capable of handling missing data and combining heterogeneous data types. Latent structures with multiple layers are non-linear and can model complex dependencies between the independent variables and the risk to churn. The hierarchical generative approach makes use of deep exponential families (DEFs). This class of models is able to extract a hierarchy of dependencies between latent variables. Similar to deep unsupervised feature learning, this analysis can improve predictions and provide extra insights into the nature of the data. The hidden layers in the DEFs enable the exploration of interesting structures in datasets. These patterns could help sales representatives in classifying customers according to their risk of churn, so that companies or managers can take more well-informed decisions.

4 - Inferior member participation prevention in online research communities
Steven Debaere, Kristof Coussement, Tom De Ruyck

As firms recognize an online research community (RC) as a valuable resource for integrating external consumer knowledge into innovation processes, they increasingly ignore temporal interaction borders and support long-term collaborations. However, in the pursuit of a long-term RC, moderators face enormous challenges, especially due to inferior member participation. Inferior member participation, whether in the form of inferior participation quantity and/or inferior participation quality, produces a shallow community with minimal activity and rotten community with unhelpful content, respectively. To sustain the viability of RCs on the long-term, inferior member participation must be battled effectively. Due to the data-rich RC environment, moderators increasingly turn to data-driven strategies to support community management. Proactive community management is a new moderation practice that consists of proactive identification and prevention of inferior member participation. Relying on a field test sample of four RCs, this study explores the importance of campaign characteristics (e.g. motivation and personalization) on prevention success. The results advance literature on data-driven community management practices in RCs and inform the moderator on how to implement these tactics within their own community.

■ MD-20

Monday, 15:00-16:30 - 2103

Scheduling with resource constraints

Stream: Scheduling: Theory and applications
Invited session
Chair: Jose M Framinan

1 - Order scheduling with tardiness objective: Approximate solutions
Jose M Framinan, Paz Perez Gonzalez, Victor Fernandez-Viagas Escudero

In classic scheduling literature, jobs to be processed are treated as individual entities possibly belonging to different customers, and hence the objectives sought are related to the completion times of the individual jobs, or to the differences between the completion times and their due dates or deadlines. However, in many real-life situations, a customer order is composed of several, different products (jobs) that have to be processed in the shop, and it makes sense to pursue objectives related to the completion of the order as a whole rather than to the individual jobs in the order. The branch of scheduling focusing in determining the schedule of the jobs with one/several objective(s) related to the orders (i.e. to sets of jobs) is denoted as order scheduling. Despite the practical and theoretical relevance of this problem, the literature on order scheduling is not very abundant, although several contributions exist regarding the objectives of minimising the weighted sum of completion times of the orders, the number of late orders, or the total tardiness of the orders. In this paper, we focus in the last objective, which is known to be NP-hard and for which some heuristics exists. More specifically, we propose a new, extremely fast heuristic based on incorporating a look-ahead mechanism, and a matheuristic able to provide extremely good solutions if longer CPU times are allowed.

2 - Scheduling problems minimizing makespan with periodic maintenance
Paz Perez Gonzalez, Jose M Framinan, Victor Fernandez-Viagas Escudero

In this work we present different mixed integer linear programming models (MILP) for the scheduling problem where machine are not available on cyclical periods due to maintenance activities or off-periods like weekends. Our interest in this problem is based on a real case where operations are not started if it cannot be finished within a shift. In this case, operations are non resumable. The problem for a single machine with non-resumable periodic maintenance and objective makespan (SMPM) has been shown NP-hard in strong sense.

Therefore, most of the research effort has concentrated on providing approximate procedures, but, to the best of our knowledge, not models to solve small instances optimally have been published in the scheduling literature. Although SMPM can be seen as a bin-packing problem (BP), in this paper we shown that it is an assignation and scheduling problem, comparing the MILP for the problem SMPM to the MILP for BP. Additionally, we try to determine the influence of the length of the availability interval before each periodic maintenance activity (T) in the scheduling aspect of the problem. For this reason, we carry out a Design of Experiments. Results reveals that the problem is more similar to the BP for smaller values of T, and the scheduling has more influence for larger values of T.

3 - A population-based constructive heuristic for the permutation flowshop scheduling problem

Victor Fernandez-Viagas Escudero, Paz Perez Gonzalez, Jose M Framinan

The permutation flowshop scheduling problem, consisting of determining the sequence of n jobs which must be processed on the m machines of a shop following the same order, is one of the most studied problems in Operations Research, and the problem addressed in this contribution. There are several reasons for the relevance of this problem: On the one hand, the flowshop layout is the common configuration in many real manufacturing scenarios, as it presents several advantages over more general job shop configuration, and, in addition, many job shops are indeed a flowshop for most of the jobs. On the other hand, many models and solution procedures for different constraints and layouts have their origins in the flowshop scheduling problem. All these elements stress the importance of finding efficient algorithms for this scheduling problem. In this contribution, we present a population-based constructive heuristic to solve the permutation flowshop scheduling problem to minimise total flowtime. The algorithm works with several individuals in parallel in each iteration. It iteratively constructs individuals adding jobs at the end, combines them and selects the best x ones. Since the individuals are formed by partial sequences, a forecast index is introduced in order to be able to compare individuals with different un- and scheduled jobs.

4 - Approximation algorithms for machine scheduling problems with non-renewable resource constraints

Tamas Kis, Péter Györgyi

Non-renewable resources, like raw materials, semi-finished products, energy or money add an extra difficulty to solving machine scheduling problem, where in addition to the capacity of the machines, the availability of raw-materials, or the demands for the production of semi-finished goods have to be taken into account in the course of scheduling. In the talk we define machine scheduling problems where the jobs either consume non-renewable resources supplied over time, or produce semi-finished goods to meet demand over time. We show that the former problem with the makespan objective is equivalent to the latter one with the objective of minimizing the maximum lateness of a delivery. This implies that providing an exact, approximation, or heuristic algorithm for one of the two problem classes yield an equivalent algorithm for the other. Further on, we will present positive and negative results for the makespan minimization problem in the parallel machine environment, where jobs have to be allocated to machines, and they also require non-renewable resources for their execution. In particular, we give a complete description of the conditions when a polynomial time approximation scheme (PTAS) exists for this problem, and when it does not, provided P is not equal to NP. We will also provide computational results obtained by an exact method using some of the ideas used in our PTAS-s.

■ MD-21

Monday, 15:00-16:30 - 2104A

Maritime optimization 2

Stream: Port operations
Invited session
Chair: David Franz Koza

1 - Tighter MIP formulations for the barge container ship routing problem

Laurent Alfandari, Tatjana Davidović, Fabio Furini, Ivana Ljubic, Vladislav Maras, Sébastien Martin

We consider the planning of a line for a barge container ship. Given weekly splittable demands between pairs of ports, the problem is to decide the subset of ports to be called on the ship route and the number of containers to be shipped between each pair of ports, so as to maximize the total profit while respecting a given travel time. The repositioning of empty containers is considered in order to potentially reduce their leasing or storage costs at the ports. A single route is designed for the ship which follows the outbound-inbound principle: the pre-ordering of ports is given, and the ship has to stop at a given port before going back to the first port. We provide two new MIP formulations that are tailored for barge container ship routing in the inland waterway transport, each formulation modeling empty container flows in a different way. These models exploit the line structure of the river by associating the route variables with nodes. We also show that the approach can be extended to general maritime shipping problems that respect the outbound-inbound principle. Our models significantly outperform existing approaches from the literature on benchmark instances for barge container routing, We also provide some variants, including optimization of the turnaround time, allowing multiple round-trips, and dealing with unsplittable demands. Numerical experiments enable to compare the computational performance of the models.

2 - Tramp ship routing and scheduling with voyage separation requirements

Jesper Larsen, Richard Lusby, Charlotte Vilhelmsen

This presentation addresses a tramp routing and scheduling problem. Tramp ships operate like taxies by following the available demand, as opposed to liner ships that operate like busses on a fixed route network according to a published timetable. Tramp operators determine some of the demand in advance by ensuring long-term contracts. The rest of the demand comes from optional voyages found in the spot market. Routing and scheduling a tramp feet to best utilize feet capacity according to the current demand is therefore an ongoing and complicated problem. We add further complexity by incorporating voyage separation requirements that enforce a minimum time spread between some voyages. We developed a new and exact Branch-and-Price procedure for this problem. A dynamic programming algorithm generates columns, while a novel time window branching scheme is used to enforce the voyage separation requirements. Computational results show that the algorithm finds optimal solutions very quickly for the vast majority of test instances. We compare the results with two earlier published methods and show that our Branch-and-Price approach outperforms both an a priori path generation method and an Adaptive Large Neighbourhood Search heuristic.

3 - A column generation algorithm for the liner shipping network design problem

David Franz Koza, Guy Desaulniers, Berit Dangaard Brouer

We present a novel graph based formulation for the Liner Shipping Network Design Problem (LSNDP) that can be solved by a column generation algorithm. The LSNDP addresses two interdependent problems: the first one consists in finding a set of cyclic shipping routes (services) that offer fast port-to-port transport connections for containerized cargo; and the second problem addresses the optimal routing of containers through the service network while respecting vessel capacities and transit time limits. The goal is to maximize the difference between revenue for transporting containers between ports and the cost for operating the cyclic shipping services. The presented solution approach decomposes the problem into a commodity path pricing subproblem to generate port-to-port container paths and a service pricing subproblem to generate cyclic shipping services. The latter is a variation of the travelling salesman problem with profits and is a hard problem by itself. The master problem combines services and container paths such that vessel capacities are respected. Labelling algorithms to solve the subproblems are presented. The formulation extends existing models in several ways: It allows for different sailing speeds between ports, considers transit time and transshipment restrictions for cargo paths and calculates transshipment times exactly. Computational results are presented for instances of the LINER-LIB.

4 - A rolling horizon approach to optimally serve road containerized demand in a cooperative environment
Claudia Caballini, Simona Sacone, Ilaria Rebecchi

Horizontal cooperation among truck carriers represents a promising solution in containerized transport sector. Cooperation can contribute maximizing companies' profits, increasing efficiency of operations and decreasing the number of empty movements. The problem under consideration regards a multi-period planning in which carriers share trips over a time horizon composed of a certain number of days. It is considered the possibility of performing trips in advance or delayed with respect to their deadlines, to combine trips belonging to different carriers in different days and to perform them when it is more convenient over the whole time horizon. To this purpose, a mathematical model has been formulated and implemented. Moreover, two different approaches have been applied and compared: a fixed planning method and a rolling horizon approach. Different scenarios based on real data have been tested, considering a transportation demand dynamically varying in the considered time horizon. The results obtained pointed out the benefits provided by a rolling horizon approach in a context in which the total demand is subject to dynamic changes over time.

■ MD-23

Monday, 15:00-16:30 - 2105

Approaches for modeling and simulation of semiconductor supply chains

Stream: Modeling and simulation of supply chains
Invited session
Chair: *Lars Moench*
Chair: *Hans Ehm*

1 - Combining agent-based modeling and recursive simulation to mimic decision-making in semiconductor supply chains
Thomas Ponsignon

The competitive nature of the semiconductor industry combined with long cycle times, short product life cycles and multiple sources of uncertainty emphasizes the need for appropriate supply chain planning processes. Decision-making in supply chains usually involves a mix of human-based decisions and automated routines supported by IT tools. Human-based decisions play a crucial role where IT tools fail to capture the complexity of the market and manufacturing environment. To gain insights into the adequacy of human-based decisions we want to mimic their behaviors by combining agent-based modeling with recursive simulation. Agent-based modeling is a well-known approach that is based on autonomous agents interacting with their environment by means of decision heuristics. Recursive simulation originates from the military command and combat simulation. A recursion is defined as the simulation of a model (primary instance) and the invocation of a new simulation instance (secondary instance) of that same model from within the primary instance. The results of the secondary instance are used in the primary instance. We show how the combination of both modeling approaches may help to mimic planning decisions related to production strategies and stock targets throughout the product life cycle in the context of a semiconductor supply chain.

2 - A mathematical approach for the optimization of a supply chain in semiconductor industry
Gottfried Nieke, Dirk Doleschal, Gerald Weigert

Semiconductor industry is one of the most complex sectors of industry. This is due to its complex manufacturing processes and long overall processing times. Therefore it is necessary to optimize the manufacturing process. This counts for each production facility and as well for the whole supply chain. Optimizing a supply chain in semiconductor industry is very challenging, because of the dispersion of the facilities all over the world and the complexity of each facility. In this paper a mathematical method for optimizing a supply chain in semiconductor industry is presented. The goal is to compute near-optimal release dates for each lot by given due dates for each part of the supply chain. As objectives the tardiness, the cycle time and the earliness are used. The underlying scheduling problem is solved by constraint programming. During the solution process two different objective functions are used: a weighted sum and a multi criteria optimization. The developed method is tested with a supply chain model that contains one frontend facility, one die bank and one backend facility. The results of the optimization are compared against a simulation model using dispatching rules. Finally the results of the optimization have been simulated, to test how good they can do in practice. In summary it can be stated that the CP optimization outperforms the simulation with dispatching rules for all three objectives.

3 - Production planning formulations including process improvement activities for semiconductor supply chains
Timm Ziarnetzky, Lars Moench, Thomas Ponsignon, Hans Ehm

Process improvement activities by engineering lots are crucial to stay competitive in the semiconductor market. Engineering lots are processed to support the development of prototypes for new salable products, to improve the fabrication process, and to test and maintain the availability of the production equipment. Scarce resources require to process engineering lots in the same facilities that produce the current generation of products in high volume. Therefore, production and engineering lots compete for the same equipment. In this talk, we discuss two different production planning formulations for a simplified semiconductor supply chain. The first formulation assumes a reduced available capacity for production due to engineering activities, while the second formulation directly incorporates engineering activities. Additional capacity is considered in this formulation because of learning effects that represent process improvements. Results of applying both formulations in a rolling horizon setting using simulation are presented. The integrated formulation outperforms the conventional one with respect to profit and realized cost.

4 - Incorporating elements of a sustainable and distributed generation system into a production planning formulation for a wafer fab
Lars Moench, Timm Ziarnetzky, Jesus Jimenez

In this talk, we consider elements of a sustainable and distributed generation system for a wafer fab. The generation system includes wind turbines (WTs), solar photovoltaics (PVs), a substation with grid, and a net metering system. WTs and solar PVs have the highest priority in supplying the daily electricity of the wafer fab. Surplus energy can be returned to the main grid. The objective function of the production planning formulation contains production-related costs and cost for energy from the substation. This cost can be reduced by offering renewable surplus energy to the main grid. The obtained production plans are executed in a simulation environment in order to compute the expected profit in the face of machine breakdowns, wind power volatility, and uncertain power output of the solar PVs. The approach allows to determine an appropriate number of WTs and solar PVs for a given demand scenario. We present results of simulation experiments with the proposed formulation.

■ MD-24

Monday, 15:00-16:30 - 301A

Improving healthcare in Ontario

Stream: CORS SIG on healthcare
Invited session
Chair: Daphne Sniekers

1 - MRI wait times in Ontario - An evidence-based tool to assist allocating regional funding hours to improve decision making and patient wait times
Luciano Ieraci, Saba Vahid, Brian Ho, Kala Studens, Penny Wang, Ali Vahit Esensoy, Jonathan Norton

Purpose: CCO developed analyses to help Local Health Integration Networks examine MRI wait times in Ontario. An interactive analytical tool was created that predicts the optimal allocation of funding (scan hours) within each LHIN incorporating hospital-level performance indicators. Method: Analyses were developed using the Wait Time Information System. MRI demand was predicted for the next three years for different queues using time series analysis. A mathematical model produced optimal allocation of funding to improve two wait time performance indicators: percent of scans completed within access target; and 90th percentile wait time. Policy-relevant parameters allowed users to customize growth in MRI demand; scan efficiency and throughput; P3 waitlist reduction; and equity by balancing indicator values across hospitals. Results: LHINs use the tool to examine predicted MRI demand and the corresponding effect of performance metrics. Reductions in 90th percentile wait times for lower priority scans were observed when using optimized funding allocations. The 90th percentile wait times also decreased based on improved efficiency sand throughput; and decreased by minimizing the discrepancy in indicator values across hospitals within the LHIN of interest. Conclusion: LHINs requested a tool to assist in allocating funding for MRI scans in Ontario to improve access to services. The tool has shown the LHINs and stakeholders the value of modifying policy levers to reduce wait times.

2 - Capacity planning for community-based dementia health care services in Ontario; using administrative health care databases and agent-based simulation methods
Tannaz Mahootchi, Danielle Shawcross, Dallas Seitz, Natalie Warrick, Ali Vahit Esensoy

Prevalence of dementia in Ontario is expected to reach 220,000 by 2020, with 65% living in the community. Keeping persons living with dementia (PLwD) adequately supported at home requires expansion of community services capacity and innovative models of care. Administrative healthcare databases were used to identify PLwD in Ontario. PLwD care transitions data, their service utilization patterns, and evidence from literature was used to develop an agent-based simulation model. The model is used to analyze the planned implementation of care-partner education and support, adult day, and multi-component community support programs, specifically to estimate capacity requirements, resulting changes to PLwD transitions, and their health service utilization. If no interventions are applied, by 2020 the total number of PLwD waiting for their first long-term care (LTC) placement will increase by +80%, over 2015 estimates. However, if a scenario like care-partner education and support program were to be implemented, by 2020 total number of PLwD waiting for LTC placement can curb this increase down to +48%. To realize the effects of such an intervention, Ontario needs to build capacity for 71,507 monthly counseling hours and provide monthly support groups for at least 34,304 persons by 2020. Simulation models can be used to provide insights on the potential effects of programmatic interventions on the healthcare system while sizing the future demand and capacity needs at the system level.

3 - Forecasting Ontario provincial drug expenditures - A hybrid approach to improving accuracy
Daphne Sniekers, Paula Murray, Yusuf Shalaby, Luciano Ieraci, Helen Guo, Lucy Qiao, Aliya Pardhan, Jessica Arias

The Provincial Drug Reimbursement Program (PDRP) at CCO is responsible for monitoring actual and projected outpatient intravenous cancer drug spending in Ontario. A tool was developed incorporating time series analysis to improve forecasting accuracy and assist in tracking the drug budget throughout the fiscal year. A multiple-method forecasting approach was adopted combining automated time-series forecasting with expert-customizable input. The approach employed linear and non-linear time series techniques, and a hybrid model. An interactive tool was developed incorporating the statistical models and identified the best performing forecast according to standard goodness-of-fit measures. Model selection procedures considered both the amount of historical expenditure data available per drug policy and individual policy contributions to the overall budget. The user can customize forecasts based on knowledge of external factors related to policy or price changes, and new drugs that come to market. A comparison of FY2015 expenditures showed the tool achieved a forecasting error of 0.4%. The forecasting tool and manual forecasts previously made by the program are currently being compared and results are forthcoming. The tool will be deployed in budget forecasting for the first time in FY2017/2018. Results have shown the tool to be effective in generating accurate forecasts incorporating both automated and PDRP-informed budget projections.

4 - Implementing the resource allocation of dialysis center at Scarborough and Rouge hospital
Mina Alirezaee, Michael Carter

The Scarborough Hospital (TSH), located in the east end of Toronto, Ontario, is home to the largest Regional Nephrology Program in North America with more than 6,000 patients receiving care. Dialysis is a process for filtering blood for patients with poor kidney function. Typically, patients must attend the clinic three times per week for around four hours. Centres have a difficult time deciding how many nurses are required to monitor and manage their clients. When a complication occurs with a patient (reaction) or a machine (technical issues), a registered nurse must be available to correct the problem quickly. Dr. Mahsa Shateri recently developed an IP formulation that enables a centre to specify performance characteristics, and compute the number of nurses required to achieve a specified quality objective (time to respond to complications). Facilities have different nurse-to-patient ratio because they are unique in terms of the combination of patients and the workload policies regulating their nurses. There are no rules or standards of patient to nurse care ratio for hemodialysis patients. The objective of this project was to implement Shateri's mathematical model for the Scarborough Hospital dialysis centre and to validate the results.

■ MD-25

Monday, 15:00-16:30 - 301B

OR and ethics 2

Stream: OR and ethics
Invited session
Chair: Maryam Hafezi

1 - Humanitarian logistics in Mexico
Jaime Mora Vargas

This work presents a review of humanitarian logistics evolution in Mexico for the las 30 years, considering initiatives before and after Mexico City earthquakes occurred in 1985. That events were on September 19th with magnitude 8.1 Richter. One of the consequences of those events were the creation of Nacional System of Civil Protection which coordinates actions in order to protect population against natural or man-made disasters. Several opportunity areas are presented, related with collaborations with Universities and research centers. Also, mathematical models for decision making in disaster situations are presented where routing and distribution decisions are considered.

2 - Product line design strategies under governmental imposed policies
Maryam Hafezi

In this presentation, the effect of governmental regulations on firms' product line design decisions is investigated. Governments, by imposing standards, are trying to benefit society by preventing firms from falsely labeling products, and assuring that society will get at least minimum environmental quality by using any available product in the market. By jointly considering the interaction among the consumers' preferences, firms' product line design strategies, and regulations from government, I look at possible scenarios which will give insights to both firms and government about the effect of such regulations.

■ MD-26

Monday, 15:00-16:30 - 302A

Forecasting of renewable energy

Stream: Stochastic assessment of renewable energy
Invited session
Chair: John Boland

1 - Probabilistic forecasting of solar energy
John Boland

With the growth in use of solar energy input into the electricity grid, not only domestic, but increasingly with solar farms, robust short term forecasting of the resource is needed. Short term means at the time scales of the electricity market - sub-hourly. In Boland and Soubdhan (2015), it was shown that hourly, and also sub hourly, solar radiation data displayed an autoregressive conditional heteroscedastic (ARCH) attribute. This means that the variance of solar radiation time series varies over time but in a stochastic manner. Recent work (Grantham et al 2016) shows that there is also a systematic variation in variance, with higher variance in summer, and also in the middle of the day. Thus both approaches identify one aspect of the change in variance with time, but without dealing with the other. This paper describes methods to merge the two. Preliminary investigations have identified a likely pathway, and preliminary testing looks very promising. It is more complicated than might have been originally thought but it follows a precise algorithm. It has been tested at two sites and appears to perform well.

2 - A Markov-Switching vector autoregressive stochastic wind generator for multiple spatial and temporal scales
Amanda Hering

Despite recent efforts to record wind at finer spatial and temporal scales, stochastic realizations of wind are still important for many purposes and particularly for wind energy grid integration and reliability studies. Most instances of wind generation in the literature focus on simulating only wind speed, or power, or only the wind vector at a particular location and sampling frequency. In this work, we introduce a Markov-switching vector autoregressive (MSVAR) model, and we demonstrate its flexibility in simulating wind vectors for 10-min, hourly, and daily time series and for individual, locally-averaged, and regionally-averaged time series. In addition, we demonstrate how the model can be used to simulate wind vectors at multiple locations simultaneously for an hourly time step. The parameter estimation and simulation algorithm are presented along with a validation of the important statistical properties of each simulation scenario. We find the MSVAR to be very flexible in characterizing a wide range of properties in the wind vector, and we conclude with a discussion of extensions of this model and how it can be used to improve wind forecasts.

3 - Stochastic characterization of global solar radiation variability and its influence on forecasting errors models
Ted Soubdhan

In this work, we have led an analysis of global solar radiation variability characterisation and try to measure it's influence on forecasting models errors. To do so we have compared different metric commonly used in literature including stochastic parameters. We have then classified typical days according to their variability and performed forecasting models over these time series. Different predictions models were performed such as machine learning techniques (Neural Networks, Gaussian processes and support vector machines) in order to forecast the Global Horizontal solar Irradiance (GHI). We also include in this study a simple linear autoregressive (AR) model as well as two naïve models based on persistence of the GHI and persistence of the clear sky index (denoted herein scaled persistence model). The models are calibrated and tested out of sample data from Guadeloupe (16.25'N ; 61.58'W). The output error of the different models are quantified by the normalized root mean square error (NRSME). We will discuss on how the metric used to characterise variability can vary according to a given data and how the forecasting errors are influenced by this variability. With this analysis, global solar radiation forecasting models can be selected according to variability of the data and hence the meteorological conditions.

■ MD-27

Monday, 15:00-16:30 - 302B

Behavioural issues in decision making 1

Stream: Behavioural OR
Invited session
Chair: Gilberto Montibeller

1 - Capturing preferences for fairness in resource allocation problems
Nikolaos Argyris, Ozlem Karsu, Alec Morton

We consider the problem of a central planner choosing among different distributions of resources across different parties. A wealth of behavioural evidence has demonstrated that a fairness in the distribution of resources may be an overriding concern in practice. We consider how such concerns may be incorporate in the decision making We take an axiomatic approach: we construct an "equitable preference ordering" which combines structural assumptions relating to efficiency and inequality-aversion with explicit preference data from a survey, past policies, or the planner's paternalistic views. We show that the set of all such functions that rationalise the preference ordering has a succinct polyhedral characterisation. This can be used to compute the subset of equitably-efficient distributions. We show how these results can be used to introduce fairness constraints in optimisation formulations of resource allocation problems (e.g. to stipulate that the optimal distribution must equitably-dominate another reference distribution).

2 - Any bias in spatial decision-making processes?
Valentina Ferretti

The need and interest to consider cognitive and motivational biases has been recognized in different disciplines (e.g. economics, decision theory, finance, risk analysis, to name the most relevant ones) and has recently reached environmental decision making. Within this domain, the intrinsic presence of a spatial dimension of both alternatives and criteria calls for the use of maps throughout the decision-making processes in order to properly represent the spatial distribution of the features under analysis. This makes spatial decision-making processes a particularly interesting domain to explore new dimensions of behavioural and cognitive biases. The talk will present insights from a literature review on cognitive biases in spatial decisions, as well as some preliminary results from a first behavioural experiment on the spatial dimension of biases carried out in the Behavioural Lab of the London School of Economics and Political Sciences. The aim of the experiment is to understand whether or not and to which extent the use of spatial information can bias the preference elicitation phase of a decision-making process. The results of the experiment are expected to have implications for spatial planning and decision making procedures, by generating better awareness on the meta-choices available to decision analysts and planners when designing Spatial Decision Support Systems, as well as on the consequences of these meta-choices.

3 - Bayes and prejudice
Detlof von Winterfeldt

When judging probabilities, people ignore statistical base rates and confuse conditional probabilities. For example, when judging the likelihood of fatal pitbull attacks on humans, they think of dramatic examples, ignoring the fact that fatal dog attacks are very rare, by pitbulls or other breeds. They also confuse the probability of an attack, for any given pitbull (which is very low) with the probability of a pitbull being among the group of attack dogs (which is fairly high). Ignoring base rates and confusing conditional probabilities contribute to prejudice against minorities among dogs and humans.

4 - On the effectiveness of debiasing overprecision in probabilistic estimates
Gilberto Montibeller, Valentina Ferretti, Detlof von Winterfeldt

The appraisal of complex policies often involves alternatives that have uncertain impacts, such as in health, counter-terrorism, or urban planning. Many of these impacts are hard to estimate, because of the lack of conclusive data, few reliable predictive models, or conflicting evidence. In these cases, decision analysts often use expert judgment to quantify uncertain impacts. One of the most pervasive cognitive biases in those judgments is overconfidence, which leads to overprecision in the estimates provided by experts. In this paper we report on our findings in assessing the effectiveness of best practices to debias overconfidence in probabilistic estimation of impacts. We tested the use of counterfactuals, hypothetical bets, and automatic stretching of ranges in three experiments where subjects were providing estimates for general knowledge questions. Our findings confirmed results from previous research, which showed the pervasiveness and stickiness of this bias. But it also indicated that more intrusive treatments, such as automatic stretching, are more effective than those merely requiring introspection (e.g. counterfactuals).

■ MD-28

Monday, 15:00-16:30 - 303A

Healthcare logistics

Stream: OR in healthcare
Invited session
Chair: *Stefan Nickel*
Chair: *Teresa Melo*
Chair: *Brigitte Werners*

1 - Optimal allocation of ambulances and simulation based evaluation
Brigitte Werners, Pia Mareike Steenweg, Lara Wiesche

A sufficiently large number of ambulances have to be allocated to emergency bases so that emergencies can be reached within a given time frame. Empirical studies have shown temporal and spatial variations of emergency demands as well as variations of travel times during the course of a day. Therefore, varying numbers of ambulances are required. In location and allocation planning models, several aspects can be integrated and respective optimal solutions on a tactical level are determined. In particular our model, which optimizes the empirically required coverage and uses flexible locations, determines sophisticated solutions. To evaluate the consequences of such solutions on an operational level and to convince different interest groups, comprehensive simulation studies are conducted. Dynamics, multi-criteria and uncertainty of the real world setting are taken into account. Comparisons of solutions can by supported by their respective distribution functions of significant criteria combined with stochastic dominance considerations as well as by graphical representations for practitioners. The theoretical considerations are exemplified by using real world data from a German city. It can be shown that our research results are well suited to improve emergency medical service systems.

2 - Robust multi-class multi-period scheduling of MRI services with wait targets
Akram Mirahmadi Shalamzari, Houra Mahmoudzadeh, Hossein Abouee Mehrizi

In recent years, long wait times for healthcare services have become a challenge in most healthcare delivery systems in Canada. This issue becomes even more important when there are priorities in patient's treatment which means some of the patients need emergency treatment, while others can wait longer. One example of excessively long waiting times in Canada is the MRI scans. This is partially due to limited capacity and increased demand, but also due to sub-optimal scheduling policies. Patients are typically prioritized by the referring physician based on their health condition, and there is a waiting time target for each priority group. The difficulty of scheduling increases due to uncertainty in patient's arrivals and service times. We develop a multi-priority robust optimization (RO) method to schedule patients for MRI services over a multi-period finite horizon. First, we present a deterministic mixed integer programming model which considers patient priorities, MRI capacity, and waiting time targets for each priority group. We then investigate robust counterparts of the model by considering uncertainty in patients' arrivals. Finally, we apply the proposed robust model to a set of numerical examples and compare the results under different scenarios.

3 - A robust optimization approach for outpatient admission planning
Nazanin Aslani, Onur Kuzgunkaya, Navneet Vidyarthy, Daria Terekhov

Admission planning is a key tactical decision for a re-entry appointment system in an outpatient setting. Admission planning focuses on finding an optimal admission scheme through managing the fixed available capacity. We consider this problem with two patient types, first-visit and revisit, both of which have lead-time targets. Demand of both first-visit and re-visit patient types is uncertain. To deal with this uncertainty, we propose a robust admission planning approach based on the methodology of Bertsimas & Sim (2003). The results have practical implications on the management of an outpatient setting.

4 - Designing response supply chain against bioattacks
Peter Yun Zhang, Nikolaos Trichakis, David Simchi-Levi

Bioattacks, i.e., the intentional release of pathogens or biotoxins against humans to cause serious illness and death, pose a significant threat to public health and safety due to the availability of pathogens worldwide, scale of impact, and short treatment time window. In this paper, we focus on the problem of prepositioning inventory of medical countermeasures (MCM) to defend against such bioattacks. We introduce a two-stage robust optimization model that considers the policymaker's static inventory decision, attacker's move, and policymaker's adjustable shipment decision, so as to minimize inventory and life loss costs, subject to population survivability targets. We consider a heuristic solution approach that limits the adjustable decisions to be affine, which allows us to cast the problem as a tractable linear optimization problem. We prove that, under mild assumptions, the heuristic is in fact optimal. Experimental evidence suggests that the heuristic's performance remains near-optimal for general settings as well. We illustrate how our model can serve as a decision support tool for policy making. In particular, we perform a thorough case study on how to preposition MCM inventory in the United States to guard against anthrax attacks. We calibrate our model using data from multiple sources, including publications of the National Academies of Sciences and the U.S. Census.

■ MD-29

Monday, 15:00-16:30 - 303B

Military, defense and security applications 2

Stream: Military, defense and security applications
Invited session
Chair: *Arjun Madahar*

1 - **A PRICIE (+G) analysis working group online collaboration and planning tool for the Canadian Army: Methodology and application**
Emile Pelletier

The PRICIE (+G) Evaluation, Aggregation and Review (PEAR) tool for the Canadian Army (CA) assists military project and capability management Offices of Primary Interest (OPIs) with planning CA Force Development Working Groups (CAFDWGs). These CAFDWGs, also called PRICIE (+G) analysis working groups, are held to discuss the introduction of new capabilities into the CA with the aim of identifying all the factors involved in this complex process. PRICIE (+G) is a hierarchical framework and its top level elements are: Personnel; Research; Infrastructure; Concepts; Information; Equipment (and Generate). The PEAR tool assists with the collection and organization of topics and discussions which are sorted into the PRICIE (+G) framework. Designed in SharePoint and Microsoft InfoPath, using online surveys, the PEAR tool allows experts participating in the CAFDWGs to share their ideas in advance. One survey in the PEAR tool allows the opportunity for experts to comment on all contributed topics. Another survey collects importance assessments to assist the OPIs to plan the agenda of the CAFDWG. The PEAR tool also calculates levels of agreement between experts' assessments of the importance of topics, using the reliability measure known as Krippendorff's alpha. The allows the OPIs planning the CAFDWG to gauge whether a given topic might take extra time to discuss.

2 - **Senior defence decision-making: A game theoretic conceptual approach for improved cooperation**
Renée Kidson, Stephan De Spiegeleire, Alan Dupont, Brent Haddad

This talk presents a game theoretic conceptual approach for improved senior Defence decision-making. While the initial target is capability investment, the approach may be more broadly applied to situations of counterproductive rivalry. Our approach involves converting apparently competitive, zero-sum games into cooperative games with mutually beneficial outcomes to maximise national interest, the ultimate objective of Government. In many countries, Defence consumes a sizeable portion of national budget. Fiscal pressures affect funding allocation to Defence capabilities, a process often occurring in a Defence Committee. One impediment to optimum investment decisions is widely-recognised interservice rivalry (e.g. where Navy, Army and Air Force compete). Economists term this a principal-agent problem; whereby the principal (Government) has difficulty judging the impartiality of advice from any agent with fundamental self-interests (e.g. a military service chief) and often exclusive domain expertise. Results can include inefficient investment and compromised national interest. Repeated waves of Government reform targeting Defence (to achieve efficiencies or improved 'jointery') are symptomatic of this unresolved principal-agent problem. Game theory can help illuminate an expanded solution space; identify mechanisms fostering enhanced cooperation; and elicit behaviours which improve outcomes. The paper is relevant to Government officials, Defence professionals and analysts.

3 - **The three steps analysis method for joint operations**
Chifei Zhou

The three steps analysis method is researched for joint operations. The first step is forces analysis, to make sure better attack effects of opposing sides. The second step is actions analysis, to ensure better results of forces cooperation and actions. The third step is plan analysis, to confirm better uses of the forces at different conditions. After three steps analysis, we can get better choice for joint operations.

4 - **Prioritising policies, through force structure risk & affordability analysis: The UK strategic defence & security review**
Arjun Madahar

Increasing pressure on the Defence budget and a more uncertain world were key themes during the UK's Strategic Defence and Security Review (SDSR) 2015. The SDSR considered various policy options, each of which was assessed for its suitability and practicality. Part of this assessment process required senior decision makers to understand the impact that a proposed policy would have on future force structures. A suite of tools has been designed that is able to provide valuable insights on the affordability, capability and capacity risk of a force structure. The tools use techniques such as linear programming, dynamic & static concurrency analysis and cost growth assumptions to provide an evidence base to support policy assessment. Key to our success has been collaborative working with senior decision makers and the close relationships we have established. This presentation will give an overview of the tool suite, how it was used to support SDSR15 and how our method of working has led to success.

■ MD-30

Monday, 15:00-16:30 - 304A

Forest value chain design 1

Stream: OR in forestry
Invited session
Chair: *Foroogh Abasian*

1 - **Development of an economically sustainable and balanced tactical forest management plan: A case study in Quebec**
Azadeh Mobtaker, Mustapha Ouhimmou, Mikael Rönnqvist, Marc Paquet

In Canada, most of the forests are publicly owned, and forest products companies depend on timber licenses issued by the provincial governments for their wood supplies. Since April 2013, a new forest management regime came to effect in the province of Québec; now the government is responsible for harvest area selection and timber allocation. This complex tactical planning decision has great impacts on downstream economic activities. In order to avoid "creaming" of the forest resources and to determine a sustainable tactical plan ensuring a stable level of availability of supply, quality and cost over several years, it is necessary to simultaneously take several criteria into consideration. In our project the considered resources were harvest areas with their specific attributes in terms of size, volume, species composition and average tree size. The goal was to integrate three important criteria over the whole planning horizon while satisfying specific logistic constraints. Thus, we employed the idea of business and anticipation periods to balance resources over a long period. We propose a goal programming MINLP model and solved it for a real case in the province of Québec by BARON solver. Results show the proposed model outperforms conventional sequential cost minimization strategy by ensuring a more balanced use of wood supply and costs for all stakeholders over a longer period.

2 - Dry kiln scheduling regarding the integrated value chain problem for sawmills

Maria Anna Huka, Marc-André Carle, Sophie D'Amours, Mikael Rönnqvist

Drying of timber holds an optimization potential due to the high costs of energy expenditure. The problem of drying timber in kilns can be separated in a machine scheduling and a bin packing sub problem. The first sub problem solves the dry kiln scheduling problem by assigning packages to drying chambers. The second sub problem, the bin packing problem needs to deal with certain conditions which have to be met within the drying chamber such as stacking and placement restrictions, different drying schemes and dimensions. Thus, varying batches can be assembled and assigned to kilns. The important aspect is the integration of the drying process into the production planning at a sawmill. Thus, the processes are planned simultaneously to achieve customers demand under the restriction of the available raw material of the processes before. Furthermore, the inventory of timber will differ because either timber is going to be stored without drying, dried right after sawing, or it will go to an intermediate storage between sawing and drying. Hence, the time for completion is depending on the dry kiln assignment too. The integrated optimization problem is divergent, complex and standard MIP solvers fail to produce a good solution in a reasonable amount of time. Two different decomposition approaches are presented in order to find good solutions in reasonable computation time.

3 - Investigating approaches to strategic network capacity design using mixed integer mathematical programming

Narges Sereshti, Eldon Gunn

Considering forest industry, different elements, such as available forest resources, manufacturing plants and mills, and customers constitute links in a value chain. Strategic forest network design deals with optimizing the potential performance of this chain. Although many decisions in this network may have high impact on each other, they are made independently. These decisions consist of forest management, capacity expansion, and network flow problem. Considering forest management and the network design problems including capacity expansion, we can address two approaches to deal with them. The first approach, which is the current approach in Canada, is the sequential approach in which the forest management is done as a separate decision making process. In the second approach, which is an integrated approach, the forest management problem is considered as a part of the network design problem and in a single decision making process. The goal of the present research is to investigate these two decision making approaches, using mathematical models and laboratory data sets. The result of this research will be used to discuss the necessity of an integrated decision making process to find strategic options for integrated industry capacity in a network design context which are consistent with forest management and final products' market.

4 - Forest biorefinery network design under uncertainty-case study in Newfoundland

Foroogh Abasian, Mikael Rönnqvist, Mustapha Ouhimmou

The forest industry is transforming itself along new product development by utilizing forest biomass. However, a smooth transformation depends on stabilizing the current state of the network and consideration of possible future changes. In this regards, we propose a two-stage stochastic optimization model to evaluate the proficiency of locating new biorefinery and terminals to an existing forest supply chain taking into account uncertainty in the demand and price of products. The model decomposes strategic and tactical decisions in first and second stages, respectively. Assessment of potential bio-processes, as well as using new assortments at potential locations are considered as strategic decisions. Meanwhile, harvesting decisions, network flows, mill's activity level and fluctuation on demand and price of products are included in tactical decisions. A multicut L-shaped decomposition method is implemented to provide the most profitable network design for possible future scenarios. We compared the stochastic and deterministic solutions by calculation of the value of stochastic solution. Moreover, financial risks including value at risk and downside risk are quantified. Finally, the proposed model and algorithm are demonstrated through a case study in Newfoundland, Canada.

■ MD-31

Monday, 15:00-16:30 - 304B

Energy management applications

Stream: Energy economics, environmental management and multicriteria decision making

Invited session

Chair: Thomas Volling

1 - Piecewise linear bounding for energy optimization in hybrid electric vehicles

Sandra Ulrich Ngueveu

Different energy sources can have very different characteristics in terms of power range and energy demand/cost function also known as efficiency function or energy conversion function. Introducing these energy sources characteristics in combinatorial optimization problems results into mixed-integer non-linear problems neither convex or concave. Approximations via piecewise linear functions have been proposed in the literature. Non-convex optimization models and heuristics exist to compute optimal breakpoint systems subject to the condition that the piecewise linear continuous approximator never deviates more than a given delta-tolerance from the original continuous separable function over a given finite interval, or to minimize the area between the approximator and the function. We present an alternative solution method based on the upper and lower bounding of energy conversion expressions using discontinuous piecewise linear functions with a relative epsilon-tolerance. We prove that such approach yields a pair of mixed integer linear programs with a performance guarantee. Models and heuristics to compute the discontinuous piecewise linear functions with a relative epsilon-tolerance will also be presented. Computational results have shown the efficiency of the method in comparison to state-of-the-art methods on instances derived from the literature and on real-world instances from various energy optimization problems such as energy optimization in hybrid electric vehicles.

2 - Impact of temperature extremes on electricity demand: A case study

Caston Sigauke, Murendeni Nemukula, Delson Chikobvu

Recently the sub-Saharan region has experienced extreme heat waves. This phenomenon requires use of extreme value theory distributions in predicting the frequency of occurrences of these hot spells. In this paper we explore the use of boundary corrected extremal mixture models in modelling heat waves using South African temperature and electricity data. We show that as temperature increases and converges to its upper bound, the marginal increases in electricity demand also converge. This modelling approach helps system operators in scheduling and dispatching of electricity during the heatwave period.

3 - Welfare optimal nominations in passive gas networks and associated equilibria

Julia Grübel, Jonas Egerer, Veronika Grimm, Lars Schewe, Martin Schmidt, Gregor Zöttl

We study the relation of equilibria in natural gas markets under perfect competition and the solution of a corresponding single-level welfare maximization problem. The understanding of this fundamental relation between equilibria and welfare maximal solutions is a prerequisite for an analysis of the current entry-exit gas market design in Europe. The behavior of the three main players - gas suppliers, gas consumers and the regulated transmission system operator (TSO) - is modelled by mixed complementarity problems. We therefore obtain a mixed nonlinear complementarity system for the wholesale short-run natural gas market. As gas flow through pipelines is inherently nonconvex due to gas physics, classical first-order optimality conditions are rendered insufficient. We state economic and technical assumptions under which the equilibria of the mixed nonlinear complementarity system exist and correspond to the solutions of the single-level welfare maximization problem. Furthermore, we analyze the welfare maximization problem as well as its dual variables with regard to uniqueness. The focus is especially on the uniqueness of the duals of the flow conservation constraints as this is a basic requirement to define economically meaningful nodal prices.

4 - Energy-oriented scheduling of identical parallel machines considering a two-part tariff system
Thomas Volling, Lukas Strob

We propose a mathematical model (MILP) for the energy-oriented scheduling problem with identical parallel machines. The model considers time-dependent labor costs and costs for electric energy while simultaneously determining optimal job assignments, job sequences and machine operation modes. A two-part energy contract is assumed, consisting of a time-varying energy rate as well as a rate that is charged depending on the peak load. We present results of an application-oriented numerical example comparing the performance of the model with a conventional scheduling approach minimizing labor costs. The results indicate that under a wide range of conditions significant cost reductions can be achieved. The potential is especially pronounced, if the degree of capacity utilization is low to medium and job durations are short.

Monday, 16:45-18:15

■ ME-01

Monday, 16:45-18:15 - 307B

Applications of heuristics

Stream: Applications of heuristics
Invited session
Chair: *Geir Hasle*
Chair: *Lukas Bach*

1 - An effective tabu search approach for multi-objective scheduling of flexible manufacturing systems
Seyed Sina Miri Nargesi, Arash Mohammadi, Sepideh Farazmand Far, Azadeh Bolourchi Hossein Zadeh, Soheil Lamei Javan, Bahman Pirhayati Rouzbahani

Flexible manufacturing system (FMS) is an automated manufacturing system consisting of a set of numerically controlled machines with automatic tool interchange capabilities, linked together by an automated material handling system. In the present study, a multi-objective model for flexible manufacturing systems using a Tabu Search (TS) approach has been proposed. The model which presented in this paper had three objectives including minimization of mean job tardiness and mean job earliness; the third one was minimization of mean machine idle time, simultaneously. FMS scheduling problem is strongly non-deterministic polynomial-time (NP)-hard problem and is usually difficult to find its optimal solution. Regarding the issue that the proposed model is in the class of NP-hard combinatorial optimization problem, we utilized a Tabu Search approach as a meta-heuristic algorithm to overcome the complexity of the model. Next, a test problem in small and large sizes has been applied to show the superiority of the methodology over previous approach. Finally, the computational results showed that the proposed TS algorithm presented in this paper is very effective for both small and large size of the problems. For the extension of this work, certain techniques such as fuzzy theory or multi-criteria decision making or multi-objective methods can be used to adjust the weights of the model. Further research should include developing other heuristic approaches for scheduling FMS.

2 - Dynamic preprocessing for the airline manpower problem
Björn Thalén, Per Sjögren

The pilot manpower planning problem consists of the long term planning of recruitment and promotion to meet the forecasted crew need. The major complication of this problem is that many airlines have a strict seniority model for promotions of pilots, i.e., a pilot who has worked longer at the company should always be promoted first, if the pilot prefers the position. Additionally, resources used for training are both limited and very expensive. In addition, most airlines have the option to distribute work between months using e.g. vacation and overtime giving the problem a high impact linear elements making it more complicated to solve with an integer based meta-heuristic method. Formulating the problem as a Mixed Integer Program has the complication that even with a good model, setting up the whole problem for a medium sized airline the number of columns would be around 1 million and the number of constraints around 100 million. I will focus on different preprocessing methods to reduce the problem enough to be able to tackle with a very large neighborhood matheuristic method. The main preprocessing is in itself using a matheuristic scheme that iterates to heuristically find a problem that is small enough and still contains the optimal or near-optimal solutions. Substantial savings has been seen by airlines using the Jeppesen Manpower product and I will also talk about how the mathematical methods were realized and used to tackle the very complicated real life problem.

3 - Annealing metaheuristic approaches to the 3D printer head problem

Seán McGarraghy, Terry Harrison, Adrian Doyle, Peter Hannon

3D printer head moves may be non-extrusion (positioning head) or polymer extrusion (boundary or fill of area between boundaries). The 3D Printer Head Problem is to optimise 3D printing time by minimising the head's non-extrusion distance travelled. It is a constrained CO problem closely related to the TSP. A tour is a sequence of extrusion moves, viewed as extended vertices. The start and end of an extended vertex need not be the same point: thus the direction of an extrusion move affects the head location on completing that move, and so affects the total non-extrusion travel time. Extrusion moves cannot be omitted or shortened; however, their sequence may be reordered subject to constraints, and an extrusion move's direction may be reversed. Constraints are: each extrusion move is carried out exactly once; related boundary moves are grouped; a fill move must succeed the two boundaries between which it fills; non-extrusion moves are assumed to be straight lines. For each slice of the 3D object, the objective function to be minimised is the sum of Euclidean distances between the end point of extrusion move i and the start point of extrusion move i+1. We apply Simulated Annealing (SA) and Quantum Annealing (QA), with neighbours generated using k-opt. We find that the total non-extrusion distance can be optimised by both SA and QA. QA outperforms SA both in terms of algorithm runtime and printer time savings realised, provided good metaheuristic parameters have been found.

4 - Optimal design for a series-parallel system: Replacement policy to improve system reliability
Daoud Ait-kadi, Zouheir Malki, Nabil Nahas

Generally, optimal redundancy allocation is the best way to improve reliability systems. The problem of this allocation consists of the selection of the combination of component type and redundancy level in order to achieve a given reliability level with respect to a number of constraints. Components are characterized by their reliabilities which are usually assumed to be constants. In real life, systems and their components degrade with time and use. In order to address this problem, we propose in this paper a preventive replacement policy for a series-parallel system. Under this policy each parallel subsystem is completely replaced if a number of failures occur. We first take into account of this policy in the problem modeling and we solve the problem with Simulated Annealing Heuristic. The results show that the establishment of the replacement policy gets a better reliability system and more economic design.

■ ME-02

Monday, 16:45-18:15 - 308B

Data mining and big data analysis

Stream: Data science and analytics (contributed)
Contributed session
Chair: *Kwang-Jae Kim*

1 - Ranking from textual data
Andrey Kateshov, Alexander Grigoriev, Nalan Baştürk

Rankings are important decision tools in modern society. Examples of commonly ranked items include universities, consumer products, music albums among others. The common way to rank is to order items based on a score of weighted sum of certain criteria. The choice of these weights is inherently subjective. It appears difficult if not impossible to advocate for the use of one set of weights over the other. In this work we look at the algorithms capable of creating rankings without the supply of any kind of supervised parameters, such as criteria weights. We argue that these algorithms can also take information already widely available on the Internet as an input. Examples of such information include Internet discussion forums, Twitter, media outlets and other sources of textual information. The most trivial way to rank a set of terms based on the textual data is to count how many times each term was mentioned and then order the terms accordingly. We compare this approach to an algorithm called HITS, that was previously used to rank web pages, and another method based on Minimum Linear Arrangement (MinLA), a well known NP-hard problem. To our knowledge this is the first time HITS and MinLA are used with textual data. We study the properties of all three approaches given various statistical assumptions on how the input data is generated. Finally, we provide an empirical study of their performance given a data collected from an Internet forum that discusses universities.

2 - Identifying significant keywords based on diversity indices
Dohyun (Norman) Kim, Nagyoon Song, Chungmok Lee, Jinseo Park

Keyword analysis is often used to investigate the intellectual structure of scientometrics. When conducting the analysis, it is critical to extract significant keywords from publications. TF-IDF is a representative index to identify significant publication keywords based on term frequency and document frequency. Developed in this article is new indices to identify significant keywords based on two diversity indices including Simpson and Stirling indices. Experimental results show that the proposed indices perform better than existing indices including TF-IDF irrespective of the data set and can be used as useful alternatives when extracting significant keywords in keyword analysis.

3 - Process mining methodology for the development of user-oriented projects
Yaimara Céspedes González, Patricia Arieta Melgarejo

Use of information technologies has become widespread in society, particularly use of information systems, which allow to automate the processes and store the data associated with the execution of these processes. As consequence, currently, there is a growth in the digital universe of data that is driving the need to find new ways to analyze and process data sets to obtain useful knowledge. Precisely, one of these technologies is process mining, which provides methods for discovering, analyze, monitor, improving processes, and identify business opportunities. Currently, there are tools to perform process mining, as well as methodologies that allow to carry out projects of this type. Nevertheless, although these methodologies with different approaches and performance fulfill the main objective of guiding the knowledge discovery through analysis of event logs, these partially cover the stages of application and reduce the participation of users in each of the phases that comprise. Therefore, exist the need to define the stages that must be present in a process mining methodology to discover, monitor, and improve business processes. Precisely the objective of this research is to identify the phases of a process mining project and involve the user in each of these phases, following an iterative cycle, divided into specific stages that include analysis, design, modeling, evaluation, and result presentation.

4 - System informatics-based services: Recent cases and research issues
Kwang-Jae Kim, Chie-Hyeon Lim, Jun-Yeon Heo, Minjun Kim, Ki-Hun Kim, Chang-Ho Lee

Various types and massive amounts of data are being collected in various industries with the rapid advancement of data collection technologies. Such a big data proliferation has provided new service opportunities. For example, heavy equipment manufacturers monitor, diagnose, and predict product health through prognostics and health management services using the data collected from heavy equipment. Consequently, equipment managers can cope with potential product breakdowns and maximize product availability for clients. System informatics-based services (SISs) refer to a new class of services, where the main contents and values are created based on the analysis of the data collected from the system in question. The emergence of SIS cases can be observed in diverse industries. In this talk, we will first review a few recent research projects for developing new SISs in automobile, marine transportation, and healthcare industries. A typical SIS process undergoes three phases: data acquisition, data analytics, and service provision. We will discuss several major research issues associated with the main phases of the SIS process, including which data to collect, how to collect and manage them, how to analyze them, which information to extract, and how to utilize the information in designing and developing new services. This study is expected to contribute to understanding and realizing new service opportunities in this data-rich information economy.

■ ME-05

Monday, 16:45-18:15 - 203

Stochastic model 1

Stream: Stochastic modeling and simulation in engineering, management and science
Invited session
Chair: Hiroshi Toyoizumi

1 - An equilibrium arrival-time distribution for a discrete-time single-server queue with acceptance period and general service time distribution
Yutaka Sakuma, Hiroyuki Masuyama, Emiko Fukuda

In this study, we consider a discrete-time first-come first-served single-server queue with an acceptance period and no early arrival. The total number of arriving customers is Poisson distributed random variable, and their service times are generally distributed random variables. Customers are assumed to choose their arrival times with the goal of minimizing their expected waiting times. We obtain an arrival-time distribution of customers which achieves the equilibrium mean waiting time. From some numerical examples, we show that the equilibrium mean waiting time tends to increase in the coefficient of variation of the service time distribution.

2 - Error bound for the QBD approximation of a two dimensional reflecting random walk
Masahiro Kobayashi, Hiroyuki Masuyama, Yutaka Sakuma, Atsushi Inoie

We consider a two dimensional reflecting random walk on the nonnegative integer quadrant. It is assumed that this reflecting random walk has skip free transitions. In general, it is difficult to obtain the stationary distribution of two dimensional reflecting random walk.We are concerned with the error estimation of the stationary distribution of two dimensional reflecting random walk assuming that the stationary distribution exists. We derive a error bound for the QBD approximation of such a two dimensional reflecting random walk.

3 - Numerical computation of the stationary queue length in the M/G/1+PH queue
Yoshiaki Inoue

We consider a stationary M/G/1 queue with impatient customers, whose impatience times follow a phase-type distribution. Usually, this model is denoted by M/G/1+PH, where the last symbol represents the impatience time distribution. The main purpose of this talk is to present a computational algorithm for the queue-length distribution. We note that the M/G/1+PH queue encompasses, as a special case, the M/PH/1+PH queue. The queue-length process of the M/PH/1+PH queue can be formulated as a continuous-time level-dependent quasi-birth-and-death (LDQBD) process by regarding the queue-length as the level-variable, and the state of the phase-type random variables representing the remaining service time and the remaining impatience times as the phase-variable. However, in this LDQBD process, the number of phases grows exponentially as the level increases. Therefore, it is difficult to compute the stationary queue-length distribution in the M/PH/1+PH queue using general computational algorithms for the stationary distribution of LDQBD processes. In this talk, another approach to compute the queue length distribution is presented, which can be applied to the M/G/1+PH queue. We show that the queue length distribution in the M/G/1+PH queue is given in terms of the virtual waiting time distribution, and based on it, we construct a computational algorithm for the queue-length distribution that also outputs an upper-bound of numerical error due to truncation.

4 - Priority queue and limit order book
Hiroshi Toyoizumi

We use simple a simple M/M/1 priority queue to analyse traders' behaviour in a stock market driven by limit order book (LOB). Traders place their sell-order selecting the prices in the LOB. The sell-orders with different prices will be put into two queues, and wait to be executed with a matching market buy-order. The lower-price queue is given the priority, and each queue is served by first-come-first-serve manner. In this way, LOB can be modelled by a M/M/1 priority queue, and we can derive the expected reward for traders taking into account the cost of waiting. We derive the convergence of trader's behaviour toward the neighbourhood of the unstable Nash equilibrium.

■ ME-07

Monday, 16:45-18:15 - 204B

Heuristics for routing

Stream: Vehicle routing
Invited session
Chair: Francesco Carrabs

1 - Impacts in solutions of the vehicle routing problem generated by different optimization criteria: An experiment with simulated annealing
Arnaldo Vallim

This article intends to develop a better understanding of how optimal solutions may behave as the objective of a combinatorial problem is modified. To evaluate this question, an experiment studied two levels of changes in the objective function of the classic Vehicle Routing Problem - VRP, using the metaheuristic Simulated Annealing (SA) to solve a set of benchmark VRP instances. In terms of variations in the objectives of the operation, in the first case the aim was the classical minimization of the total distance. The solution obtained with such objective was taken as a reference to be compared with the solutions that emerged from the other types of objectives. In the second case, it was tested the minimization of the total tons.kilometer of the operation, which represents a measure of the production effort. This indicator considers not only the distance but also, the weight carried by the vehicles. Such function is a better representation of the total resources employed in the operation, which are "minimized" in the solution found by the metaheuristic SA. The third type took a different approach, considering the maximization of the level of homogeneity of the indicator tons.kilometer among the defined routes, which is a strategy to ease planning activities. The impacts of these types of objective functions were measured and an analysis of these differences was conducted showing very interesting findings, presented in the paper.

2 - An algorithm for solving the deterministic Vehicle Routing Problem (VRP) using the combination of three sequential heuristic and optimization rules
Luis Moreno, Javier Diaz, Julian Gonzalez

Based on the known priority rule for the Traveling Salesman Problem (TSP) that searches the closest not visited neighbor for each node (myopic strategy), a deterministic algorithm is proposed that uses sequentially an additional heuristic rule and an optimization algorithm to solve the VRP. After a solution of the TSP is obtained by the priority rule, an improvement is made by using a heuristic algorithm that searches the longest distance in the solution, removes it to obtain a chain and from the two resulting ends, the shortest distance to one of the other nodes in the chain is searched. Using these two edges the circuit is reconstructed in an iterative process until it is not possible to do further improvements in the solution of the TSP. Finally, an optimization problem is executed based on the previous TSP solution. The circuit is split generating feasible routes for vehicles according to its capacity. This step is repeated starting from all the nodes in order to have enough and different candidate routes for the vehicles, and an integer programming problem is solved to minimize the total distance traveled by the fleet of vehicles, using a reduced set of constraints that establishes that each node has to be visited once. The solutions obtained in these three steps are very close to the optimal or best known solutions for problems in the classical library http://comopt.ifi.uni-heidelberg.de/software/TSPLIB95/ and are obtained in a very short time.

3 - A hybrid approach for the two-dimensional vehicle routing problem with balanced load
Pol Arias, Daniel Guimarans, Gilbert Laporte

The two-dimensional vehicle routing problem (2L-VRP) is a realistic extension of the classical vehicle routing problem where customers' demand is composed by non-stackable items. Different loading configurations (unrestricted or sequential), and the possibility or not to rotate items, define the four problem variants present in the literature. All of them consider the feasibility of packing items in the vehicle's surface, given a set of routing and limited loading constraints. However, none addresses the optimisation of the packing subject to additional and realistic loading constraints (e.g., maximum weight per axle). Moreover, no variant considers load balancing and driving stability, a problem trucking companies need to face in daily operations. We propose a novel 2L-VRP extension considering these additional loading constraints. We also aim at better balancing the load and increasing driving stability by optimising the load weight location on the vehicles' surface. We denote this problem as two-dimensional vehicle routing problem with balanced load (2BL-VRP). We present a hybrid approach that uses a Constraint Programming formulation for solving the packing problem at every step of the route construction and during local search. We propose a set of extended 2L-VRP benchmark instances considering additional load balancing and weight constraints to assess our methodology.

4 - A matheuristic for the set orienteering problem
Francesco Carrabs, Claudia Archetti, Raffaele Cerulli

The Set Orienteering Problem (SOP) is a single vehicle routing problem where the customers are grouped in clusters and a profit is associated with each cluster. The profit of a cluster is collected if and only if at least one of its customers is visited in the tour. The profit of each cluster can be collected at most once. The SOP is defined on a complete directed graph in which a cost is associated with each edge. We assume that the costs satisfy the triangle inequality. The cost of a tour is given by the sum of the cost of the edges it traverses. The SOP consists in finding the tour that maximizes the collected profit and such that the associated cost does not exceed a fixed threshold. In this work we introduce a matheuristic based on a tabu search which solutions are improved through a MIP model. The preliminary results show that the mathehuristic is fast and finds high quality solutions on small instances, where an optimal solution is known.

■ ME-08

Monday, 16:45-18:15 - 205A

Demand and price learning for RM

Stream: Revenue management and pricing
Invited session
Chair: *Wei Wang*
Chair: *Ravi Kumar*

1 - Bayesian optimal exploration and exploitation in dynamic pricing
Jue Wang

Pricing under uncertain demand function is common in practice yet remains a well-known challenge in revenue management. Current literature predominantly focus on heuristics or policies that are asymptotically optimal. In this talk, we show that one can efficiently compute the optimal pricing and learning policy in a realistic situation known as the incumbent price problem. With a prior on the unknown price sensitivity, we find the optimal exploration-and-exploitation policy by solving a two-dimensional Bayesian dynamic program. We further characterize the structure of this optimal policy and discuss the managerial implications.

2 - Price learning and optimization for airline revenue management
Ravi Kumar, Wei Wang

Many airlines have been actively looking into class-free demand control structures, which requires demand models where price varies over a continuous interval. As evidenced both in literature and in practice one of the big challenges in this setting is the trade-off between policies that learn quickly and those that maximize expected revenue. We investigate applicability of recent advances in the area of optimal control with learning. We examine a demand model where customers maximum WTP is modeled as Gaussian and study approaches that generate sufficient variability in pricing to ensure discovery of the underlying customer behavior while providing appropriate level of expected revenue.

3 - Effective demand normalization to reduce price-dependent predictor variables
Amanda Xu, Pan Chen

Accurate demand forecast (i.e., demand as a function of price, or demand function) is the foundation of many aspects of business planning and operations such as inventory control and price optimization. One challenge with demand function estimation is to take into consideration of all the potential factors influencing demand volume, while dealing with limited historical data. A further challenge in practice is that many of these factors have different frequencies of changes, leading to limited variability in the modeling data. While normalization is often used to resolve such challenges, this paper reviews different modeling approaches to best normalize these factors and proposes a new demand normalization approach to effectively reduce price-dependent variables during the normalization process. The benefit of the proposed approach is to allow businesses to better understand price elasticity and focus on other key business decision variables.

■ ME-09

Monday, 16:45-18:15 - 205B

2017 IFORS prize for OR in development 2

Stream: 2017 IFORS prize for OR in development
Invited session
Chair: *Mikael Rönnqvist*
Chair: *Ke Liu*
Chair: *Richard Larson*
Chair: *Mario Guajardo*
Chair: *Víctor Parada*
Chair: *Jan van Vuuren*
Chair: *Guillermo Durán*
Chair: *Roman Slowinski*
Chair: *Peter Bell*
Chair: *Sue Merchant*

1 - A decision support methodology to obtain the most of pedagogical resources in Brazil: Efficient education through optimal teacher/student/class/school allocations
Joao Neiva de Figueiredo, Sérgio Fernando Mayerle, Hidelbrando Ferreira Rodrigues, Daiane DeGenaro Chiroli

This paper presents a decision support methodology to increase public school education efficiency at the municipal/metropolitan level in Brazil by optimizing the allocation efficiency of public school resources. An important consideration for efficient use of resources is the appropriate matching of supply (e.g., teachers of specific subjects, classroom availability and characteristics, and ultimately slots per school) with demand (students requiring enrollment in each grade). This dynamic matching of supply and demand conditions, namely the optimization of student/teacher/class/classroom/school matchings, has not yet been emphasized in the literature on OR applications to education and was solved through a mixed integer linear programming formulation. It represents a contribution in that the suggested methodology focuses on tactical planning, linking strategic planning of education with operations and service provision. The paper develops the conceptual framework, provides the mathematical formulation, and describes the implementation of the resulting decision support system. The paper also presents the use of the suggested methodology to help rationalize public schooling in Itacoatiara, a municipality on the banks of the Amazon River in a resource-constrained and low-HDI region of Brazil.

2 - A robust DEA-centric location-based decision support system for expanding recreovía hubs in the city of Bogotá (Colombia)
Sepideh Abolghasem, Felipe Solano, Claudia Bedoya, Lina Navas, Ana Paola Ríos, Edwin A. Pinzón, Andres Medaglia, Olga Lucia Sarmiento

Multi-sectorial community programs to promote healthy living in public spaces are crucial for building a "culture of health" and could contribute to achieving the specific 2030 agendas of Sustainable Development Goals including reduction of inequalities, provision of inclusive, safe, resilient and sustainable cities and promotion of just, peaceful and inclusive societies. In this context, the Recreovía program of Bogotá (Colombia) provides physical activity classes in parks mainly for vulnerable communities. In the present work, we address the challenge of efficiently locating new Recreovía hubs through developing a robust DEA-centric location-based decision support system (DSS) for guiding the Institute of Sports and Recreation of District of Bogotá on locating the best hubs to expand the Recreovía program throughout the city. This DSS will serve as a model for analytics-based decision making for expanding equivalent programs in other cities as well.

■ ME-10

Monday, 16:45-18:15 - 205C

Quality and information in production and inspection planning

Stream: Production management, supply chain management (contributed)
Contributed session
Chair: *Yu-Ting Tai*

1 - Weighted X-bar control chart for a non-normal process
Shih-Chou Kao

This study proposes the weighted X-bar control chart with the interquartile range (IQR) for monitoring a non-normal process, while taking into consideration the false alarm rate, special causes, outliers, and a combination of special causes and outliers that might exist within the process. The control limits are determined based on the weighting and average of the relative IQR which is derived based on the generalized lambda distribution. The study sets the weighting for each datum in the sample data by measuring their respective distances to the sample average. In addition to validating the robustness of the proposed control charts, this study also compares the detecting ability of various average-type control charts.

2 - Information economics approach to the design of multiple inspection plans
Young H. Chun

Suppose that a manufacturing factory are producing certain complex items such as IC chips, some of which are defective. Inspection errors are inevitable during a screening process; some of the defective items are accepted and other non-defective items are rejected erroneously. To reduce the inspection errors, each item is often inspected more than once. The multiple inspection plan has also known as a repetitive inspection, a sequential review, or a repeat inspection. Based on the inspection results after several round of inspections, we need to estimate the defective rate and the inspector's type I and II errors. A particularly important task in quality management is to accurately estimate the number of defective items still remaining in the lot. In the talk, we treat the multiple inspection plan as an information system and propose the optimal plan that minimizes the total cost. With four types of matrices in the information economics approach, we can consider the inspection errors, defective rates, misclassification costs, and the optimal decision. The model parameters such as the type I and II errors and the process defective rate can be easily estimated by the method of maximum likelihood.

3 - An intelligent multiple-zone machine layout method based on a fuzzy set theory and metaheuristic algorithm within a TFT-LCD bay
Teng-Sheng Su, Ming-Hon Hwang

Designing a TFT-LCD plant with an optimal material flow enables manufactures to increase the production efficiency, enhance yield and throughput as well as reduce cycle time and work-in-process (WIP). For the numerous 7.5th generation TFT-LCD plant built by TFT-LCD manufactures, how to design an intelligent plant layout has become one important factor in the modern manufacturing system. Due to the unique multiple-zone characteristic in a TFT-LCD plant's intra-bay, the facility layout problem of a TFT-LCD bay is different from that of a semiconductor bay. Furthermore, the facility layout design within a TFT-LCD bay is required to solve not only the machine grouping problem, but also the zone formation and sequence of machines problem. In this study, we propose a methodology based on the fuzzy set theory and metaheuristic algorithm to solve the machine layout problem within a TFT-LCD bay with a multiple-zone in-line stocker. An intelligent metaheuristic algorithm with a mixed integer linear programming (MILP) model is also developed. The objective aimed to achieve is to maximize in-sequence movements and minimize backtracking movements. An example is given to illustrate the proposed layout procedure and compares it with the layout results obtained by other existing layout approaches. Finally, it is our hope that the proposed approaches from this study can assist TFT-LCD designers in solving their machine layout problems of a TFT-LCD bay.

4 - Product acceptance determination based on the process capability index
Yu-Ting Tai

Product acceptance determination is a critical issue for supply chain management since that would affect the receiving and shipping of production quantities. Since the requests of manufacturing yield for most high-tech processes are stringent, processes are requested to be of high quality with very low fraction of defectives in parts per million. However, the effectiveness of conventional methods for product acceptance determination is no longer acceptable as no defective product items are contained in most samples via reasonable size. For this reason, process capability indices are widely applied to evaluate the production yield. Due to economies of scale considerations, multiple line processes are very commonly used in high-tech industries. Lot of existing research works are investigated regarding product acceptance determination for processes with single manufacturing line. However, the cases of multiple lines process should be considered since they are widely applied for providing sufficient capacity to be qualified suppliers and to fulfill due date requirements. In this paper, product acceptance determination is considered based on the yield index for multiple lines processes. Processes with symmetric and asymmetric tolerances for two-sided specification limits are discussed. For illustration purpose, a real application in a factory is included.

■ ME-11

Monday, 16:45-18:15 - 206A

Transport economics and operation

Stream: Traffic flow theory and control
Invited session
Chair: *Eric Gonzales*
Chair: *Diego Correa-Barahona*

1 - Spillover parking as a neighborhood nuisance
Eren Inci, Robin Lindsey, Murat Inan

Parking space near shops, restaurants and other destinations is often scarce or expensive in dense urban areas. Visitors may prefer to park in residential neighborhoods or other adjoining areas, thereby contributing to congestion and other negative externalities. Spillover parking problems are often addressed by imposing minimum parking requirements on businesses and other institutions, or by banning nonresidents from parking in residential areas. These policies can reduce, or even eliminate, spillover parking, but they can be economically inefficient. In this paper, we study spillover parking for the case of an urban shopping mall that is located next to a residential area, and provides limited on-site parking to shoppers for a fee. Shoppers can park either at the mall, or on the curb where they encounter search costs and traffic congestion. We compare several policies for dealing with spillover parking: curbside parking fees, regulating mall parking fees, and regulating mall parking capacity. Effectiveness of policies depends not only on the severity of congestion, but also on the proportion of trips taken by other modes (for example, in our case, by local shoppers who come by walking). They also depend on how the mall responds to the policies in pricing goods and services. Whether the socially desirable mall parking fee is above or below the mall's preferred level depends on the number residents in the area.

2 - Congestion pricing for the morning commute with heterogeneous trip lengths
Raphael Lamotte, Nikolas Geroliminis

This paper investigates the equilibrium properties of the morning commute problem at the network level with heterogeneous trip lengths. Congestion is modeled with a Macroscopic Fundamental Diagram relating the space-mean speed of a network to the vehicular accumulation. It is shown for a large class of scheduling preferences that if users have continuously distributed characteristics, the network accumulation at equilibrium is a continuous function of time. With alpha-beta-gamma preferences and under certain conditions, a partial FIFO pattern emerges at equilibrium among early and late users. This FIFO pattern is strict only within families of users having heterogeneous trip lengths and identical preferences, or vice versa. Finally, the well-established flow-maximizing pricing strategy is proven to be sub-optimal when departure time choice is considered and alternative usage-based strategies are developed based on externalities caused by travelers. With high demand intensities, pricing is shown to be even more beneficial as it stabilizes a system that may not be stable otherwise.

3 - Data-driven spatial-temporal dynamic equilibrium matching models of welfare effects from New York City taxi and Uber markets
Diego Correa-Barahona, Joseph Chow, Kaan Ozbay

With the rapidly changing landscape for taxis, ride-hailing, and ride-sourcing services, public agencies have an urgent need to understand how such new services impact social welfare. A number of analytical models have been proposed in recent years to evaluate policies in these markets: impacts of technologies on matching customers to service providers, evaluating ride sourcing operations, evaluating surge pricing policy, etc. However, many questions remain unanswered: for example, what is the relationship between the built environment, service supply, and user demand by time of day? Furthermore, data-driven empirical studies are scarce. We conduct the first empirical study to answer this question for Uber using a spatial dynamic equilibrium taxi matching model developed by Nicholas Buccholz. Given a matching friction, spatial distribution of demand activities, and service coverage, the model outputs equilibrium fleet sizes, matches, and social welfare by zone and time of day. Uber provides pickup data for a certain time period in NYC. Additional data from the Taxi Limousine Commission for yellow taxis are used to fit the model to the Uber market. The resulting model is used to provide preliminary analysis of three distinct scenarios: measuring the spatial-temporal dynamics of the impact of a large scale event in NYC, illustrating service expansion analysis for Uber in NYC, and quantifying welfare effects of technologies that reduce matching friction system-wide.

4 - Optimizing the Social Cost of Multimodal Transportation Systems with Network Models of Traffic and Transit
Eric Gonzales

Macroscopic models of traffic in cities have shown that for many networks a robust relationship exists between average vehicle flow and average vehicle density known as a Macroscopic Fundamental Diagram (MFD). This characterization of traffic conditions in a network is related to other useful measures of traffic performance, including travel time, operating costs, and pollutant emissions. A macroscopic network-wide approach is especially useful for quantifying these measures. The talk will present an approach for estimating emissions from cars and transit by linking macroscopic traffic models with driving cycles. This method can be paired with equilibrium models on the same macroscopic scale to quantify the effect of efficient pricing strategies on network-wide emissions.

■ ME-12

Monday, 16:45-18:15 - 206B

Financial mathematics 2

Stream: Financial mathematics and OR
Invited session
Chair: *Toshikazu Kimura*

1 - Study of prediction of financial instruments prices in terms of momentum effect
Yuto Otsuka, Takashi Hasuike

Recently, a lot of companies have used FinTech which means combination of Finance and Technology. For example, Mizuho Bank in Japan started "SMART FOLIO" service from 2015. It gives us how to compose each customer's portfolio. Investors can use FinTech cheaply, and hence, it becomes widespread. As a related study of FinTech, Jovina (1996) predicted profitability of five national markets' bonds using Neural Network in terms of momentum effect. Momentum effect means the tendency of rising or falling asset pricing. According to Jovina's study, stock markets' behavior is often predicted by past information. He explained the profitability of national bonds using 4 factor model proposed by Carhart (1997). However, Jovina's model has two problems. First, he predicted the profitability using only information about change of stock returns on the last and the first working day in five countries' stock markets. Based on the 4 factor model, information of how momentum effect worked should be put into Neural Network. Second, he didn't consider whether momentum effect worked or not during his observation period. Input data like stock prices should be used while momentum effect worked. This study shows accuracy of Neural Network using the proposed approach.

2 - Numerical performance of multilevel Monte Carlo with two optimization tools for options valuation
Hitoshi Inui

In this talk, we will investigate the performance of the multilevel Monte Carlo method using two mathematical tools in terms of variance reduction or computational complexity reduction for options valuation. To determine the number of simulation paths on each level, we will treat two mathematical optimization tools: the Lagrange's method and a machine learning approach.

3 - Dynamic pricing for perishable assets with price lock-in options
Kimitoshi Sato

We consider a dynamic pricing problem facing a firm that sells given initial inventories of perishable assets and has the opportunity to offer consumer options for the assets. The option allows customers to hold the price for a certain duration of time within the selling period at a small fee. It provides customers with not only flexibility and more time to purchase but also protection against price increase. Some airlines and travel companies sell the options on their tickets. In this research, we formulate a dynamic pricing with price lock-in options model as a discrete-time optimal control problem, and address how the firm should set prices for both the assets and options so as to maximize expected revenue. We also investigate the effect of selling options on expected revenue of the firm.

4 - Valuing employee stock options with a barrier option model
Toshikazu Kimura

Employee stock options (ESOs) have become increasingly popular and currently constitute a certain fraction of total compensation expense of many firms. ESOs are call options that give the option holder the right to buy their firm's stock for a fixed strike price during a specified period of time. In this paper, a continuous-time barrier option model is developed for valuing ESOs, in which early exercise takes place whenever the underlying stock price reaches a certain upper barrier after vesting. We analyze the ESO value and the ESO exercise time to obtain their solutions in explicit forms, which are consistent with principal features of early exercise, delayed vesting and random exit. For the perpetual case, these solutions are given in simpler forms and shown to be exact in the Black-Scholes-Merton formulation. Using an endogenous approximation for the barrier level, we numerically compare our approximation for the ESO value with a benchmark result generated by a binomial-tree model and the quadratic approximation previously established. From numerical comparisons for some particular cases, we see that our approximations always underestimate the benchmark results and the absolute values of the relative percentage errors are less than 1% for all cases, whereas the quadratic approximations overestimate the benchmarks with the errors less than about 2%.

■ ME-13
Monday, 16:45-18:15 - 207

Scheduling problems

Stream: Scheduling problems in logistics
Invited session
Chair: *Jorge Riera-Ledesma*
Chair: *Montaz Ali*

1 - Power of preemption: A review
Alan Soper, Vitaly Strusevich

For the problem of scheduling jobs on parallel machines, the power of preemption is defined as the supremum of the ratio of the makespan of an optimal non-preemptive schedule over the makespan of an optimal preemptive schedule across all instances of the problem. Tight bounds have been found for this ratio in identical, uniform and unrelated parallel-machine environments. This ratio has also been obtained in more general settings: where the number of preemptions of a schedule is limited rather than non-preemptive, where the objective function is the total completion time of the jobs, and where the processing of jobs is allowed to occur simultaneously on more than one machine. We refer to the latter as the power of split. More specialised results have been obtained in parametric studies, where the relative speeds of uniform machines is varied. In this paper we review the results, some of them recent and by the authors, and present new results on the power of split.

2 - Generator maintenance scheduling based on the risk of power generating unit failure
Jancke Eygelaar, Jan van Vuuren

A power utility's ability to satisfy energy demand can be influenced significantly by unexpected breakdowns of power generating units (PGUs). In most cases, such unexpected failures are also much more expensive to repair than taking planned preventative maintenance action. Maintenance of ageing PGUs, however, often is neglected due to high energy demand and low system capacity. The typical objectives pursued in the design of PGU maintenance schedules do not take these difficulties into account. Two new scheduling criteria are therefore proposed. The occurrences of PGU failures may be estimated using methods from reliability theory in which the aim is typically to quantify the probability of a system completing its intended function for a specific duration of time. Based on this theory, the first scheduling objective seeks to minimise the probability that any PGUs in the power system will fail during the scheduling window, weighted by the rated power generating capacity of each PGU. An alternative objective is also proposed which seeks to maximise the expected energy produced over the scheduling period, taking into account possible failures of PGUs in the system. The feasibility and effectiveness of these new objectives are analysed by applying it to well-known PGU maintenance scheduling benchmark systems from the literature.

3 - Simulation optimization approach for the stochastic quay crane scheduling problem
Naoufal Rouky, Mohamed NEZAR Abourraja, Jaouad Boukachour, Dalila Boudebous, Ahmed El Hilali Alaoui

This work is devoted to the study of the stochastic Quay Crane Scheduling Problem (QCSP), where the loading and unloading times of containers and travel times of quay cranes between bays are considered uncertain. The problem is solved with a Simulation Optimization approach which takes advantage of the great possibilities offered by the simulation to model the real details of the problem and the capacity of the optimization to find solutions with good quality. An ant Colony Optimization (ACO) metaheuristic hybridized with a Variable Neighbourhood Descent (VND) local search is proposed to determine the assignments of the tasks to the quay cranes and the sequences of executions of tasks on each crane. Simulation is used inside the optimization algorithm to generate scenarios in agreement with the probabilities of distributions of the uncertain parameters, thus, we carry out stochastic evaluations of the solutions found by each ant. The proposed optimization algorithm is tested first in the deterministic case on several well-known benchmark instances. Then, in the stochastic case, since no other work studied exactly the same problem with the same assumptions, the Simulation Optimization approach is compared with the deterministic version. The experimental results show that the optimization algorithm is competitive as compared to the existing methods and that the solutions found by the Simulation Optimization approach are more robust than those found by the optimization algorithm

4 - A non-linear integer programming aircraft assignment model
Montaz Ali

The fleet assignment model (FAM) is used by airlines for assigning multiple aircraft fleet types having different capacities and costs to a timetable of flight legs. A non-linear integer programming aircraft assignment model (NIPAAM) is presented, as opposed to the time-space multi-commodity network fleet assignment model (MNFAM) currently used in industry. It is shown that the assignment cost of the proposed model is similar to the cost obtained using the MNFAM. However, the proposed model has an advantage in that it specifies individual aircraft routing.

■ ME-14

Monday, 16:45-18:15 - 305

Computational mechanism design

Stream: Algorithmic/computational game theory
Invited session
Chair: *Simina Branzei*
Chair: *Aris Filos-Ratsikas*

1 - A new class of combinatorial markets with covering constraints: Algorithms and applications
Jugal Garg, Nikhil Devanur, Ruta Mehta, Vijay Vazirani, Sadra Yazdanbod

We introduce a new class of combinatorial markets in which agents have covering constraints over resources required and are interested in delay minimization. Our market model is applicable to several settings including scheduling, cloud computing, and communicating over a network. This model is quite different from the traditional models, to the extent that neither do the classical equilibrium existence results seem to apply to it nor do any of the efficient algorithmic techniques developed to compute equilibria seem to apply directly. We give a proof of existence of equilibrium and a polynomial time algorithm for finding one, drawing heavily on techniques from LP duality and submodular minimization. We observe that in our market model, the set of equilibrium prices could be a connected, non-convex set. To the best of our knowledge, this is the first natural example of the phenomenon where the set of solutions could have such complicated structure, yet there is a combinatorial polynomial time algorithm to find one.

2 - Optimal planning for container pre-staging and flow rates at seaport rail terminals in the present of uncertainties
Ying Xie, Dongping Song

The growing traffic volume puts a huge pressure on container ports. Traffic congestion and emissions caused by lorry movements in the surrounding areas of ports have raised serious concerns to the society. Each tonne of rail freight reduces carbon emissions by 76 per cent compared to road and each freight train removes 43 to 76 lorries from the roads. Improving the use of rail at seaport terminals, and improving efficiency of rail terminal operations, are considered as important elements in reducing pollution and congestion in container transport chains. Daily seaport rail terminal operations are large and complex, and decisions in these areas need to be made in the presence of uncertainties. This talk considers the optimal planning problem for container pre-staging and flow rates at seaport rail terminals subject to uncertainties. Pre-staging refers to moving containers from storage yards to rail terminal buffer in advance. Flow rates refer to container movements between rail terminal and storage yards during the discharging and loading time windows. The problem is formulated into a stochastic dynamic programming model to minimize the total logistics cost. Three solution strategies are presented, including optimal strategy, decoupled strategy and bang-bang strategy. Numerical experiments based on a real case study are conducted to compare these strategies and illustrate their effectiveness and sensitivity to system parameters.

3 - Deep learning for predicting human strategic behavior
James Wright, Jason Hartford, Kevin Leyton-Brown

Predicting the behavior of human participants in strategic settings is an important problem in many domains. Most existing work either assumes that participants are perfectly rational, or attempts to directly model each participant's cognitive processes based on insights from cognitive psychology and experimental economics. In this work, we present an alternative, a deep learning approach that automatically performs cognitive modeling without relying on such expert knowledge. We introduce a novel architecture that allows a single network to generalize across different input and output dimensions by using matrix units rather than scalar units, and show that its performance significantly outperforms that of the previous state of the art, which relies on expert-constructed features.

■ ME-15

Monday, 16:45-18:15 - 307A

Optimization methods

Stream: Continuous optimization (contributed)
Contributed session
Chair: *Jacques Desrosiers*

1 - Non-linear conjugate gradient method for vector optimization
Luis Roman Lucambio Perez, Leandro Prudente

In this work we propose conjugate gradient method for unconstrained vector optimization problem. Conjugate gradient methods constitute an important class of first order algorithms for solving the unconstrained optimization problem when the objective function is continuous differentiable. Due to the efficiency of the algorithms, particularly in large dimensions, the extension to the vector case appears naturally. We introduce standard and strong Wolfe conditions in the context of vector optimization. We show that exist intervals of step-sizes satisfying the Wolfe conditions along any descent direction. This new theoretical result shed light on algorithmic properties and suggest implementation of a Wolfe-type line search procedure. We also introduce the Zoutendjik condition for vector optimization and prove that general descent line search method with Wolfe-type line search fulfill this condition. The considered assumptions are natural extensions of those made for the scalar case. We present the general scheme of nonlinear conjugate gradients method for vector optimization, and study its convergence for different choices of the parameter. The analysis covers the vector extensions of five of the most famous choices in the scalar case. The methods are globally convergent. We emphasize that the Wolfe and Zoutendjik conditions are essential tolls to prove the convergence results.

2 - Improvements of an updating method of Lagrange multipliers in the procedure of listing FJ points for a reverse convex quadratic programming problem
Syuuji Yamada

In this talk, we propose a procedure for listing FJ points of a quadratic reverse convex programming problem (QRC) whose feasible set is expressed as the area excluded the interior of a convex set from another convex set. Several types of iterative solution methods for solving (QRC) have been proposed by many other researchers. However, such algorithms are not effective in the case where the dimension of variables is so large. One of the difficulty for solving (QRC) is that all locally optimal solutions do not always satisfy KKT (Karush-Kuhn-Tucker) conditions. In order to overcome this drawback, we introduce an algorithm for listing FJ (Fritz-John) points of (QRC). Moreover, by combining our algorithm into a branch and bound procedure, we obtain most of FJ points of (QRC). It is known that every locally optimal solutions of (QRC) satisfies FJ conditions. Hence, by utilizing our algorithm, we can calculate most of locally optimal solutions contained in the intersection of the boundaries of convex sets defining the feasible set. Moreover, by choosing a calculated locally optimal solution having the smallest value of the objective function, we can obtain an approximate solution of a globally optimal solution is obtained. Furthermore, to improve calculation efficiency of our algorithm, we propose an update method of Lagrange multipliers for convex constraint conditions. The effectiveness of the improvement has been shown by the result of the computer experiment.

3 - Optimal switching between cash-flow streams
Thomas Weber

The question of optimally switching between several deterministic cash-flow streams can be viewed as a scheduling problem for substitutable machines (or processors) with time-varying yield that can be allocated to the task of creating time-discounted value in a single job. This deterministic "multi-armed bandit problem" is formulated as a continuous global optimization problem on an interval. A complete characterization of the set of solutions is obtained in terms of an adjoint variable which measures the available continuation gain. The adjoint variable can be computed as the unique solution of an initial-value problem. For its computation we provide a recursive Picard-type algorithm which usually converges in a finite number of iterations. If multiple switching times are allowed, then an optimal policy is found by noting that the entire switching policy for one switch, up to the decision horizon, is characterized by the adjoint variable. Applying this logic backwards, successively including additional switches up to the decision horizon, leads to a natural dynamic-programming solution of the cash-flow switching problem. The results are further generalized to multiple cash-flow streams, switching costs, as well as switch-triggered cash-flow streams that arise in equipment-replacement problems. To obtain the main results we apply the recent exact characterisation of global optima on an interval by Weber (2017).

4 - The pricing problem in column generation
Jacques Desrosiers, Jean-Bertrand Gauthier

Degeneracy is a critical performance issue when solving linear programs with the primal simplex algorithm. While Dantzig's classical pivot rule accurately measures the improvement rate of the objective function, the influence on the affected basic variables is taken for granted for every non-basic variable unit change. When one ultimately realizes that not all affected basic variables can be modified, it becomes clear that the pricing rule suffers from a visibility problem in terms of the basic variable space. When trying to avoid primal infeasible directions, one should consider pivot-selection (or pricing) rules that are guided by dual optimality instead. From the dual perspective, one maximizes the minimum reduced cost that can be achieved upon dividing the set of dual variables in two subsets: one being fixed while the other is optimized. From the primal perspective, one selects a non-negative combination of variables entering the basis. The direction is uniquely completed by identifying the affected basic variables, if any. In this presentation, we examine some properties of four alternative pricing problems for a column generation algorithm. These are based on the following solution strategies: The Improved Primal Simplex algorithm, the Minimum Mean Cycle-Cancelling algorithm for network flow problems, the Dynamic Constraint Aggregation for set partitioning models, and the Linear Fractional Approximation scheme for the master problem.

■ ME-16
Monday, 16:45-18:15 - 308A

Operations finance interface 2

Stream: Operations finance interface
Invited session
Chair: Anne Lange

1 - Optimum premium for service contracts for damage protection and delays in delivery
Amitava Mitra

Customers of products prefer to insure their goods against damage occurred during the transportation and delivery process and also for not meeting delivery dates. A service provider offers such protection by charging a premium. For protection against damage, this is usually based on product value.A truncated probability distribution is assumed for the value of goods shipped.The conditional probability of product damage is chosen to be a function that is inversely proportional to the product value.It is assumed that the service provider will offer a volume discount to the purchaser.The problem is to determine the premium such that the expected revenue at least exceeds the expected payout. Customer preferences in modeling their behavior to purchase damage insurance is assumed to be influenced by the product value. For modeling penalty in missing due dates, an asymmetric loss function is assumed since costs associated with early deliveries and late deliveries are not necessarily the same.

2 - Modelling the venture capitalist-entrepreneur relationship
Thomas Archibald, Edgar Possani

Entrepreneurs create start-up companies with financial support from investors. The entrepreneur provides the idea for the new venture and is seeking to establish the viability of the company. The investor provides the capital required for the venture and is seeking a good rate of return. Hence, the objectives of the entrepreneur and the investor may be conflicting. The agreement between the entrepreneur and the investor specifying the initial investment and the timing and form of repayments influences the entrepreneur's behaviour and subsequently the investor's return and the survival of the company. An agreement which ensures that there is a good chance of survival when the entrepreneur devotes a lot of effort to the development of the company might be expected to beneficial to both parties. Using Markov decision processes to model the situation, this paper investigates how the nature of the agreement between the entrepreneur and the investor influences the entrepreneur's actions and the outcomes for both parties.

3 - Impact of banking and forward contracts on renewable energy certificate market
Ryo Ito, Ryuta Takashima

Recently various policies for reducing greenhouse gas emissions have been implemented by concerns about global warming and climate change. In the power industry, some policies for supporting and promoting renewable energy have been adopted in each country or region, e.g., feed-in tariff, feed-in premium, and renewable portfolio standards (RPS). Particularly the RPS scheme has been introduced in 74 states/provinces/territories in 2015. In regions where the RPS scheme is adopted, there is usually secondary markets for renewable energy certificate (REC). If power producers can not meet the RPS target, the producers require to increase a ratio of renewable energy source by means of increase/decrease in renewable/non-renewable energy generations or purchase of the REC. Tanaka and Chen (2013) analyze an interaction between the RPS policy and the power market equilibrium. They investigate an effect of the competitive equilibrium on power and REC prices. Xu et al. (2016) examine how contracts as banking and option affect market prices for carbon emission permit. They show that the contracts reduce the price volatility. We develop models for the REC market under conditions in which power producers satisfy the RPS requirements and extend the models to consider banking and forward contracts. We also analyze the impact of banking and forward contracts for the markets. For the result, we show that adapting banking and forward contracts could make the market more efficient.

■ ME-17
Monday, 16:45-18:15 - 309A

DEA and performance measurement 1

Stream: DEA applications
Invited session
Chair: Joseph Paradi

1 - Efficiency measurement of university research groups, a problem of shared outputs
Sonia Avilés-Sacoto, Wade Cook, David Güemes-Castorena, Francisco Benita, Joe Zhu, Hector Ceballos

Data Envelopment Analysis (DEA) is a methodology for evaluating the relative efficiencies of a set of decision-making units (DMUs) based on their multiple inputs and outputs. The original model assumes that DMUs operate independently of one another, meaning that the inputs and outputs of one DMU are in no way connected those of any other DMU. In this article we present a situation where some DMUs collaborate with others to create common sets of outputs. We examine the specific case of research groups in a Mexican university, Tecnológico de Monterrey. The inputs used are professors belonging to the various groups, and outputs are research articles published. Articles can take two forms, namely those created by researchers within a group, and those jointly authored by researchers from two or more groups. In modeling the efficiency of a DMU, it is normally the case that the frontier of best performers is fixed in place. In the case of the research groups, however, outputs jointly held with other groups must be considered. Specifically, it is necessary to acknowledge that the projection to the frontier of a DMU having with such jointly held outputs must be accompanied by projection of its collaborating partner at the same time. This can mean that the projection is made to a non-fixed frontier. A model for recognizing such joint projections is presented and applied to 41 research groups.

2 - Objective identification of technological returns to scale for data envelopment analysis models
Mohammadreza Alirezaee, Ensie Hajinezhad, Joseph Paradi

Here, we consider one of the most important problems for setting up a data envelopment analysis model: the identification of suitable returns to scale (RTS) for the data. We refer to it as the technological returns to scale (TRTS) to completely separate the technology's RTS from the DMU's RTS. The only existing objective approaches for the TRTS identification are statistical based. While they are supported by strong theories, they might be problematic in practice. So, we introduce a novel and objective non-statistical method for the identification of the data's TRTS. We call it the Angles method since it uses the angles between the hyperplanes to calculate the gap between the constant and variable TRTS assumptions. The gap is calculated for both the increasing and the decreasing sections of the frontier. The larger the gap in the increasing and/or the decreasing sections of the frontier, the more the TRTS approaches the increasing and/or the decreasing assumptions. The major novelty aspect of the proposed approach is the determination of the TRTS by using only the dataset without any statistical assumptions. Moreover, the rate of increase or decrease of the TRTS is represented by using the introduced gap in the Angles method. For the validation test of the proposed method, we examine 6 one input/one output cases. Also, we test the proposed method using real world data from Bank Maskan of Iran.

3 - A cross-country efficiency analysis framework for assessing banking operating environments
Skarleth Carrales, Jamal Ouenniche

Several DEA studies investigated the efficiency of banks. So far, no attempt has been made to investigate the relative efficiency of the operating environments of banks. This paper fills this gap by proposing a cross-country efficiency analysis framework. Several stakeholders could use the proposed framework. For example, governments could use this analysis framework to find out about the relative efficiency of their banking environment and then use their relative rank to either incentivize more bankers to consider investing in their country, if its operating environment is efficient enough, or reengineer their banking environment to improve its relative efficiency to attract foreign investors.

4 - Comparing pension funds and mutual funds by using mixed variable DEA
Joseph Paradi

DEA is considered to be one of the most useful techniques for managers who wish to measure some dimension of operating efficiency of financial institutions. Although DEA has been used for such evaluations, it has never been utilized for comparing financial institutions where the basic "cultures" are different. It follows that there does not exist a model that can appropriately consider different environments for various products in the same industry. This research introduces a novel DEA model, namely Mixed Variable DEA (MV-DEA) that provides an environment where DMUs with different assumptions are examined relative to each other and together while maintaining their own specific characteristics. The model was applied to Canadian private pension funds which are regulated federally and Canadian open-ended mutual funds which are regulated in a very different manner. The results of the new MV-DEA model were compared to traditional DEA models and it was shown that the MV-DEA model provided a more credible analysis.

■ ME-18

Monday, 16:45-18:15 - 2101

Enumeration problems and applications 2

Stream: Game theory, discrete mathematics and their applications
Invited session
Chair: Yasuko Matsui

1 - Enumeration and evaluation for the single-seat constituency system
Keisuke Hotta, Kawahara Jun, Takashi Horiyama, Shin-ichi Minato

The most important thing of the political districting problem in Japan is to reduce the vote-value disparity. For given m seats and the graph, the problem is to make the m-connected components. The objective is to reduce the ratio between the maximum population and the minimum among components. The optimization technique is useful to achieve the purpose. In 465 members of the House of Representatives, 289 members are elected by the single-seat constituency system. At first, 289 members should be apportioned to 47 prefectures (Japan has 47 prefectures) in proportion to the population by optimization to reduce the disparity, and then the optimal districts can be obtained in each prefecture. All problems can be solved exactly, not approximately, by optimization. The optimal solutions give us the limit of the disparity between values of votes in different constituencies. All problems can also be enumerated quickly by frontier-based search. Thus, we can evaluate each solution by several other features. For example, deviation among constituencies, the robustness for the population movement in the future, similarity between cities which belong to one electoral district, difference from the current electoral district, and so on. They can be used to provide the judgment materials to decide the political redistricting. In this research, we produce the results and the evaluation on the latest data. It is a great support for the decision-making.

2 - Fast enumeration algorithms for induced trees in graphs
Kunihiro Wasa, Hiroki Arimura, Takeaki Uno

By improving computer performance, we can easily obtain a vast amount of data that forms a graph. However, it is difficult for us to extract useful substructures or regularities hidden in the data because of the enormousness. To overcome this difficulty, we have to develop efficient methods for handling such enormous data. In this talk, we focus on acyclic substructures that widely appear in real world graphs, and explain our enumeration algorithms for such substructures. These algorithms can output all acyclic substructures that satisfy a given condition without duplications. It includes induced tress and maximal induced trees.

3 - Enumerating geometric partitions using oriented matroids
Hiroyuki Miyata

Given a family C of curves, we consider how a finite point set in the plane can be separated by the curves in C. When C is the set of lines, possible partitions of the points can be treated in the framework of oriented matroids and many enumeration results are available. In this talk, we discuss how to treat the cases when C is the set of degree-k polynomial functions and when C is the set of circles. We propose frameworks to treat those cases using oriented matroids. Based on those frameworks, we enumerate possible partitions of point sets in the plane by those curves.

4 - Optimization and enumeration of decision trees from massive data sets
Hiroki Arimura, Kazuhito Osabe, Takeaki Uno

Data mining is a study of efficient methods for extracting useful knowledge from massive data. Decision tree induction is one of the most popular data mining methods, and has been studied extensively since 1980s. In this talk, we give a survey of exact optimization algorithms for finding small and accurate decision trees based on enumeration method under a set of constraints, namely, the maximum depth and size, and the minimum leaf support, that is, the minimum number of entries classified to a leaf. Most common way of discovering a decision tree from data is a greedy method, called TDIDT (top-down induction of decision trees), such as CART (Breiman et al., 1984) and ID3 (Quinlan, 1986). In spite of the practical efficiency and accuracy of TDIDT, there is no guarantee of the optimality of discovered trees due to its greedy nature. For this problem, Nijssen and Fromont (2010) recently proposed exact algorithm DL8 for finding optimal decision tree under constraint. One biggest problem with DL8 in practice is its exponential memory consumption in the input size for avoiding duplicated computation. In the remainder of this talk, we discuss how to solve the memory problem by DFS over a subclass of decision trees, called ordered decision trees, and how to design a polynomial space algorithm for exactly finding optimal ordered decision trees from a data set under depth, size, and minimum leaf support constraints. We also discuss counting and sampling of decision trees.

■ ME-19
Monday, 16:45-18:15 - 2102AB

Business analytics 3

Stream: Business analytics
Invited session
Chair: *Dries Benoit*
Chair: *Kristof Coussement*
Chair: *Wouter Verbeke*

1 - Understanding heavy goods vehicles' behaviour by means floating car data
Sheida Hadavi, Tias Guns, Wouter Verbeke, Cathy Macharis

Transition from current mobility model to a smart city model raises several non-trivial challenges and requires an understanding of how travel behaviour and freight flows impact the liveability of cities is essential. Our research introduces new and measurable indicators that are straightforward to measure and provide insights into the impact of urban transport on liveability. In the context of a road tax, based on driven kilometres for heavy good vehicles, each truck in Belgium has been equipped with an On-Board Unit (OBU). The on-board unit of each vehicle reports time, position, velocity and direction of the vehicle every thirty seconds. Furthermore, the OBU data includes truck characteristics such as their weight category, plate's country code and emission standards classification of the engine (Euro class). In this research, we determine the interesting indicators for a municipality, which can be derived from this big data set of around two hundred million observations per day. We investigate the indicators with respect to entering, leaving and driving distance and times. We study distribution over time of the hours that trucks enter and leave. Moreover, we explore the entry points used more commonly by trucks. Thereafter, we discuss the definition of a spot used for loading and unloading, and demonstrate the hotspots used by trucks for this objective. Finally, the origin and destination of trucks is categorized.

2 - Detecting unobserved fraud in a new telecom product using network and spatial analysis
Dieter Oosterlinck, Philippe Baecke, Dries Benoit

A European telecommunications company launched a new quadruple play telecommunications package. This product includes five SIM cards without extra cost, to be used within a household. However, the company fears that SIM cards will be shared with people outside the household. As those people avoid paying a separate subscription, this results into lost revenue. Since only one identity in a household is known, it is not straightforward to identify misuse. Call detail record (CDR) data, including location information, will be used to identify whether the relationships within the households are true household relations. The fact that this is a completely new product implies that there are no yet known fraud cases. This means that a standard predictive analytics approach can not readily be applied. We develop a new method in order to make an assessment of the validity of the households. Based on business knowledge, different scenarios are created. Fraudulent cases are introduced into the data according to these scenarios. The predictive models achieve high predictive performance on a simulated test set. However, the real test lies in the prediction on the real household subscriptions. The first results seem promising, but a more conclusive result can only be reported after the identity of customers is researched into more detail. The latter is work in progress.

3 - A new class of relational classification techniques based on centrality measures
Dimitri Robert, Wouter Verbeke, Thomas Crispeels, María Óskarsdóttir, Bart Baesens

In this study, we develop a new type of relational classification techniques for application in networked data based on centrality measures. The aim of relational classification is to predict class membership of a node based on the class of linked or neighboring nodes. The proposed class of approaches adopts centrality measures for classification, and more specifically the weighted and unweighted versions of the node degree, betweenness and closeness centrality measures are adopted. Centrality measures provide information about the position and connectedness of a node in a network, which can be used for classification as shown in this study. The proposed approaches allow to explicitly account for the impact of higher order neighborhood nodes, which is relevant and useful since nodes can as well be influenced indirectly, e.g. by nodes connected to neighboring nodes. We present the results of an extensive benchmarking experiment in the setting of customer churn prediction, comparing the predictive performance of this new set of techniques with existing relational learning approaches. For this, different networks from telco companies are analyzed as well as datasets from papers that studied the concept of relational learners.

■ ME-20
Monday, 16:45-18:15 - 2103

Multiplicity of scheduling problems: New and updated applications

Stream: Scheduling: Theory and applications
Invited session
Chair: *Socorro Rangel*
Chair: *Hélio Fuchigami*

1 - A math-heuristic algorithm for a new parallel scheduling problem
Edson Senne

This paper presents a new production scheduling problem on unrelated parallel machines with sequence-dependent processing times, machine eligibility restrictions, and task execution synchronization, with the objective of minimizing the makespan. This real-world problem, found in manufacturing processes of cast rolling mill rolls, has the particularity that pairs of tasks must be completed at the same time. The manufacturing process uses induction heating furnaces of different sizes and melting rates. So, not all rolls can be produced in any furnace and the processing time for each roll depends on which furnace it will be produced. Due to the characteristics of furnace operation and also the different types of materials used, one roll can take advantage of the residue left in the furnace by the immediately preceding produced roll. So, the processing time also depends on the order in which the rolls are produced. Besides, some rolls are made of two different materials, which need to be ready at the same time. This synchronization constraint makes the problem even more complex and adds the possibility of reaching infeasible solutions. A mixed-integer programming formulation is presented and a math-heuristic algorithm combining relax-and-fix and iterated local search methods is proposed to efficiently solve the problem. This algorithm was tested on realistic data and the computational results obtained show that the proposed algorithm outperforms a standard MIP solver.

2 - Design of an easy-to-use computer tool for university timetabling
Jose Antonio Marmolejo, Jonas Velasco

In this work, we propose a computation tool based on spreadsheet considering soft constraints to solve university timetabling. We develop a tool using a spreadsheet that provides a feasible allocation of day, time and classroom to maximize the number of classes taught at the Institute. The types of soft constraints that make up the timetable are completely dependent on what resources the Institute has available. The main purpose of the work was to propose an alternative simple and accessible application that allows any user to use the tool developed. We proposed a solution strategy based on the development of a mathematical programming model using computational tools.

3 - A computational study of MILP models for weighted just-in-time flow shop scheduling problem
Hélio Fuchigami, Socorro Rangel

This work examines the flow shop scheduling problem with weighted just-in-time performance measures, including the income of completing the jobs on time and earliness/tardiness penalties. According to the just-in-time concept, early or tardy deliveries are strongly avoided while timely delivery of products is highly encouraged. The problem is formulated as different mixed integer linear programming models, based on diverse paradigms like sequence-based and position-based formulations. The performance of the mathematical models was investigated and compared in terms of computational efficiency (evolution of CPU time with the increase of instances sizes), in several instances using a commercial software. Four different scenarios were considered for the generation of intervals for due dates of jobs, covering diverse range settings.

■ ME-21

Monday, 16:45-18:15 - 2104A

Maritime optimization 3

Stream: Port operations
Invited session
Chair: Jose M. Belenguer

1 - A mathematical formulation for the pre-marshalling problem
Consuelo Parreño Torres, Ramon Alvarez-Valdes, Ruben Ruiz

The pre-marshalling problem consists in sorting the containers placed in the storage area of a container terminal in such a way so that they can be retrieved afterwards without any additional reshuffling. The objective of the problem is to minimize the number of moves in the shuffling process that leads to a final disposition in which the containers are directly available according to the loading sequence. Reshuffling can be done before the arrival of a ship, when the work load at the terminal is minimum, so that no shuffling needs to be carried out when ships are being loaded/unloaded, thus increasing the performance of the terminal when it is most needed. Although numerous methods for solving the pre-marshalling problem have been proposed in the scientific literature, only one integer formulation has been proposed for this problem to the best of our knowledge. In this work, we have developed a new mathematical formulation, reducing the number of variables and proposing different sets of valid inequalities that enhance and improve the performance of the model. In order to assess the contribution of each type of valid inequality to the efficiency of the model and to evaluate its performance, several computational experiments have been carried out together with comprehensive statistical analyses. We have used different benchmarks for the pre-marshalling problem existing in published papers obtaining satisfactory results.

2 - A simulation-based study on trucking traffic and mitigation strategies within a maritime port
Jean-Francois Audy, Éloïse Goudreau, Chantal Baril, Viviane Gascon

A maritime port without containers is composed of several specialized and general cargo terminals for storage and transshipments, mainly between maritime and ground transportation modes. To access a terminal for cargo (un)loading, a truck entering within the gate-controlled port area will travel on a road network shared among all terminals. This shared area will be used for trucks queueing when a terminal capacity is running below its trucks arrival rate. When high level of trucking activity occurs simultaneously among the independently operated terminals (e.g. no/lack of coordination among the terminals, synchronized seasonal peak patterns of different cargo), significant congestion may appear leading to increase in average truck turn time (i.e., waiting time increase). Conducted at the Port of Trois-Rivières (Canada), this research analyzes the inbound and outbound trucking traffic of thirteen types of cargo in order to target which cargo is generating the higher level of trucking activity and where on the road network (hot spots). Supported by observations work in the field, a discrete event simulation model of this trucking traffic inside the port area has been developed and validated. Trucking traffic mitigation strategies (e.g., truck appointment systems) have been set with both the terminal operators and the administrative port authority. The test of these strategies with the simulation model resulted in decrease in average truck turn time.

3 - Heuristics for the yard crane scheduling problem in a port container terminal
Fulgencia Villa, Eva Vallada, Jose M. Belenguer, Ramon Alvarez-Valdes

In this work, heuristics are proposed for the yard crane scheduling problem in a port container terminal. Containers in the yard are accessed through multiple input/output points located at both the seaside and the landside, and congestion in inputs/outputs is considered. Two problems have to be solved: on the one hand, to schedule the containers in the crane and, on the other hand, to assign an input/output to each container. Four types of operation requests related to containers are analyzed: arrival of a container from a vessel to be stored in the yard, arrival of a container from land to be stored in the yard, retrieval of a container from the yard to be loaded in a vessel, and retrieval of a container from the yard to be loaded in a truck. The optimization objective is the total weighted delay according to a time parameter related to each container. A benchmark of instances is also proposed considering small, medium and large instances. An experimental evaluation is carried out using the proposed benchmark and the results are analyzed by means of statistical analysis in order to identify which heuristics show the best performance.

4 - A matheuristic for the yard crane scheduling problem in a port container terminal
Jose M. Belenguer, Ramon Alvarez-Valdes, Eva Vallada, Fulgencia Villa

In this work, we study a problem arising at a container terminal, consisting of scheduling a yard crane to carry out a set of container storage and retrieval requests in a single container block with multiple input/output points located at both the seaside and the landside. We have to schedule the containers in the crane and, simultaneously, to assign an input/output to each container, taking into account the possible congestion in both sides of the block. The objective function is a weighted combination of the delays, taking into account the time in which a container arrives to the block to be stored and the time in which a container in the block is required at the seaside or landside. Two mathematical models are developed for this problem, considering it as a routing problem and as a machine scheduling problem. We have also developed a matheuristic scheme in which the best performing model is embedded to solve instances of larger size. Benchmark instances are also proposed and used to test models and algorithms.

■ ME-23

Monday, 16:45-18:15 - 2105

Stochastic models of supply chains

Stream: Modeling and simulation of supply chains
Invited session
Chair: *John Fowler*
Chair: *Scott Mason*
Chair: *Ozias Ncube*

1 - Simulation-based scheduling for the slitting lines of a steel coil producer
Evrim Gencalp, Onur Can Saka, Kaan Esendağ

A single-machine scheduling problem for the slitting lines of a steel coil producer is examined in this study. The slitting process involves cutting of coils across the length and width in order to obtain narrower and shorter products. The dimensions of initial and final products are highly variable. The slitting process is decomposed into tasks each of which is performed by a specific operator. There exist dependencies among the tasks and some tasks can be executed in parallel. Order and duration of tasks depend on product and process characteristics. A discrete-event simulation model is developed to detect line stoppages and generate the time schedule for a given job sequence. The simulation model is embedded in a heuristic scheduling algorithm which aims to increase line productivity by minimizing line stoppages while satisfying time and precedence constraints for certain jobs. The achieved results through computational experiments are presented.

2 - A real options approach for joint overhaul and replacement strategies with mean reverting prices
Alejandro Mac Cawley, Maximiliano Cubillos, Rodrigo Pascual

One of the key decision in physical asset management is to define the equipment overhaul and replacement strategy, due to its significant impact on the economic performance in capital-intensive industries, such as the mining industry. Classical approaches define periodical interventions based on the equipment physical condition, considering factors such as availability and operation costs. These fixed models generally ignore two important aspects: first, the possibility to reevaluate the decision to overhaul or replace in a given period, not taking into account the flexibility in the decisions and second, the uncertainty of economic factors, such as price, which can affect future maintenance decisions. This work contributes by taking into account the effect of integrated price uncertainty in joint overhaul and replacement strategy definition using a real option approach and a mean reversion binomial model for the uncertainty in the price. To achieve this objective, we develop a real option model and determine an optimal intervention policy which maximize the expected profit. To obtain such a solution we use a backwards recursion algorithm. A numerical case study for the mining industry to validate the effectiveness of the proposed methodology is presented. Results show that the option-based decision model economically outperforms the classical fixed strategy approach and recommends a different equipment overhaul and replacement strategy.

3 - Modelling supply chain performance in the presence of sustainability induced constraints
Ozias Ncube

Complex supply chains are susceptible and hence vulnerable to different disturbances. Of late, supply chains are being interrogated from a sustainability paradigm. With the advent of global supply chains, it has become imperative that supply chain performance is not appraised from a financial or on-time delivery perspective alone, but that the supply chain aligns and conforms to sustainability tenets - economic, social and environmental. This breeds a new regime of constraints that impact significantly on the ability to determine an appropriate optimisation model for supply chain performance. In this paper, a stochastic model is used to determine an optimal supply chain performance in the presence of sustainability induced constraints. Different scenarios reflecting different combinations of the degree of willingness and or ability to fulfil the three sustainability conditions are evaluated. The solution to each scenario is presented as "best case", degree of vulnerability and corresponding contingency or mitigation strategy for each combination of parameters identified. A simulated example is used to illustrate the performance of this model for fast moving consumer goods (FMCG) oriented supply chain

■ ME-24

Monday, 16:45-18:15 - 301A

Scheduling and capacity planning in health

Stream: CORS SIG on healthcare
Invited session
Chair: *Jonathan Patrick*

1 - Setting wait time targets in a multi-priority clinical setting
Vusal Babashov, Antoine Sauré, Jonathan Patrick

In Canada, priority-specific wait time targets for healthcare services are mandated by provincial ministries of health. Facing limited resources and trade-offs between wait times and the ability to use resources effectively, current clinical practice is to book less urgent patients further into the future. We contend that current wait time targets force patients wait longer for no practical benefit to clinics in terms of resource management and that consequently wait time targets can be reduced without additional resource requirements. The objective of this research is to derive a model that would allow managers to determine appropriate wait time targets that provide sufficient flexibility without forcing patients to wait longer for no real benefit. Given that the most appropriate wait time targets ought to depend on capacity, the concurrent objective is to determine optimal regular and overtime capacity to provide quality service to patients at minimum cost. We aim to build a stochastic mixed integer optimization model to determine the optimal regular hour capacity while also setting target wait times for each priority class. We will assume that patients are booked using the scheduling policy described earlier by Patrick et al (2008). To our knowledge, this is the first mathematical model that attempts to determine appropriate wait time targets and capacity at the same time in a multi-priority setting.

2 - Scheduling medical students to clinical rotations
Adam Diamant, Andre Augusto Cire, Tallys Yunes

Medical students at the American University of the Caribbean School of Medicine (AUC) begin in-hospital training after passing a computer-delivered licensing exam offered on a year-round basis. To graduate, students must complete five clinical rotations at one of the twenty-five hospitals affiliated with AUC. In this work, we investigate optimization strategies to minimize the cost of student-hospital matchings. The complexity of the problem stems from the fact that hospitals differ with respect to what rotations they offer, the capacity of each rotation, the date a rotation starts, and the cost AUC is charged for instruction. Moreover, students become eligible to begin in-hospital training at different dates (i.e., when they pass their licensing exam) and have preferences regarding where they would like to train. We formulate the deterministic, multi-period, rotation scheduling problem using a mixed-integer programming model and a constraint programming model. Both balance the cost of assigning students to rotations with the cost of satisfying students preferences. To find provably optimal solutions in a computationally efficient manner, we combine these methods into a hierarchical, logic-based Benders decomposition algorithm. We show preliminary results in a numerical study that uses five-years of historical data provided by the medical school.

3 - Dynamic multi-appointment patient scheduling with resource compatibility restrictions
Antoine Sauré, Ingeborg Bikker, Nathan Horvath, Claire Ma, Scott Tyldesley

Wait times are a significant problem in health care. In radiation therapy, waits may translate into loss of local control of cancer and deterioration of quality of life. Wait times are often a direct consequence of an imbalance between capacity and demand, but also a result of inefficient patient scheduling. Highly variable demand, complex treatment fractionations and varying machine requirements, together with limited treatment capacity, make it extremely difficult for a booking agent to manually assess the impact of his/her decisions in order to more efficiently allocate capacity. This unintended lack of foresight may translate into unnecessary delays, a non-systematic prioritization of patients, unused appointment slots and excessive overtime. We formulate and approximately solve a discounted infinite-horizon Markov decision process for scheduling cancer treatments in radiation therapy units. The main purpose of this model is to identify good policies for allocating available treatment capacity to incoming demand, while reducing wait times in a cost-effective manner. We use an affine architecture to approximate the value function in our formulation and solve an equivalent linear programming model through column generation to obtain an approximate optimal policy for this problem. The benefits from the proposed method are evaluated by simulating its performance for a practical example based on data provided by the British Columbia Cancer Agency.

4 - Dynamic multi-priority, multi-class patient scheduling with stochastic service times
Jonathan Patrick, Antoine Sauré, Mehmet Begen

Patient scheduling has significant operational, clinical and economical effects on health care systems. Efficient scheduling not only increases the timely access of patients to care but also reduces costs. Appointment scheduling refers to the assignment of specific appointment times to the set of patients scheduled for a particular day while advance scheduling refers to the assignment of patients to future service days. These two problems have generally been addressed separately despite each being highly dependent on the form of the other. This paper develops a framework that combines the two problems in the context of surgery scheduling. It incorporates random arrivals with multiple patient types and priorities as well as random surgery durations. We take into account the waiting time until the day of service as well as the idle time and overtime of operating rooms/surgeons on the day of service. We use approximate dynamic programming and determine the optimal advance schedule with stochastic surgery durations. We first provide theoretical and numerical results for the case with multi-class, multi-priority patients and deterministic service times. We then adapt the model to incorporate stochastic service times and perform a comprehensive numerical analysis on a number of scenarios. We compare policies obtained from our models and benchmark policies used in practice. We also present results based on a medium-size clinic in Ontario, Canada and quantify potential savings.

■ ME-25

Monday, 16:45-18:15 - 301B

Developing knowledge economy

Stream: Knowledge as a nation development strategy
Invited session
Chair: *A. D. Amar*

1 - On the collective soul of booms and busts: A socio-dynamic theory of business cycles
Julia Puaschunder

With growing globalization and quickening of transfer speed, information may impose unknown systemic economic risks on a global scale. Collective interaction effects lead to hard-to-foreseeable fallacy of composition downfalls. Emergent risks imbued in interaction appear to be inherent of global economic systems. In the light of growing tendencies of globalization, the demand for an in-depth understanding of how information echoes in socio-economic correlates has gained unprecedented momentum. In seeking to shed light on implicit system failures' socio-economic consequences down the road and potentially-disastrous outcomes of cumulative actions triggering mass movements; the paper outlines unexpected dangers and insufficiently-described shadows of the invisible hand of the world economy in the age of globalization. Overall the following article innovatively paints a novel picture of the mass psychological underpinnings of business cycles based on information flows in order to recommend how certain communication strategies could counterweight and alleviate the building of disastrous financial market mass movements.

2 - How can nations develop knowledge economy
A. D. Amar, Daniel Goceljak

This paper answers how the rise of knowledge in workplace for designing and developing products and their transformation processes has leveled, or in many cases, tilted the playing field in favor of many nations that only a few decades ago were classified as "developing nations". We also notice that some of these nations that developed knowledge have become the benefactors of one of the greatest global wealth redistribution in the history of mankind. Advancements in technology, transportation and supply chain management have been the major drivers of this transformation. Organizational strategy has been to utilize these advancements to be able to harness the inexpensive labor sources. But just as quickly as technology has enabled many industries to chase cheap labor, it is replacing humans performing these tasks with machines. The economy of tomorrow will be driven by knowledge and the production of knowledge. All nations will need to retool their strategies to participate in the economy of the future, as it won't be driven by currency manipulation, but rather intellectual currency. Nations will need to develop knowledge organizations to reap the rewards of this future state economy. To develop knowledge organizations is not like creating a corporation of the industrial era. The assets of nations and organizations are not machines, but the tacit and explicit knowledge.

■ ME-26

Monday, 16:45-18:15 - 302A

Renewable energy and system flexibility

Stream: Stochastic assessment of renewable energy
Invited session
Chair: *Benjamin Böcker*
Chair: *Christoph Weber*

1 - Stochastic bidding of electric vehicles at different energy markets
Maren Kier, Christoph Weber

The replacement of combustion engine based vehicles by electric vehicles (EVs) leads to new challenges for the German power grid especially when EVs can provide power to the grid (V2G). Thereby it is possible to use multiple EVs as a new form of flexibility for the power grid. From the perspective of an electric utility (EU), it is important to optimize simultaneously the trading strategies for the different German electricity markets and the unit commitment of the power plant fleet including the EVs. Therefore we use a multi-stage stochastic bidding model optimizing a MIP. At the first stage, the EU makes an offer for the minute reserve power market. The second stage constitutes the day-ahead market. The optimization considers different price scenarios and produces a bidding curve for energy trading. To trade the optimal amount of electricity, technical restrictions are taken into account. After this the traded quantities are given to the model for the last stage with the unit-commitment planning. Different usage patterns of several EV-pools are used, based on the behavior recorded in the German mobility survey KiD 2010. Through trading with a virtual power plant consisting of EVs, the EU may optimize the use of the power plant fleet and achieve additional profit. The power drawn from EVs is not inducing additional costs or constraints like start-up costs or a minimum power output of a conventional starting power plant.

2 - Real time scheduling of electric vehicle charging under uncertainty

Zongfei Wang, Patrick Jochem, Wolf Fichtner

The increasing integration of electric vehicles (EVs) brings both challenges and opportunities to the power system. With uncontrolled charging, the distribution grid may reach capacity bottlenecks. Controlled charging, however, can avoid such problem and can also provide additional services to the grid, such as peak shaving and ancillary services. Therefore, it is important to have EV charging behaviors controlled and scheduled although EV availability for charging is limited and stochastic. We focus on the real time scheduling problem for EV charging with a stochastic linear programming model. The model optimizes charging behavior for multiple EVs and the objective is to try maintaining total charging demand at a predefined level. The considered uncertainty in the model is the number of EVs that will be available for charging in the future. When optimizing charging scheduling for currently available EVs, the model also considers the possibility that more EVs may be available for scheduling in future periods. Based on empirical EV usage data, EV data used in the model are simulated with inhomogeneous Markov models. Rolling window approach is applied for real time scheduling. The importance to properly select a predefined charging level is discussed. An example to participate in reserve market is given and the limit of EV charging flexibility is explained. Results show that the proposed model can schedule EV charging in real time and have total charging demand controlled.

3 - Development of a probabilistic methodology for adequacy assessment under uncertainty: Considering spatially correlated uncertainties and flow-based market coupling

Benjamin Böcker, Julia Bellenbaum, Thomas Kallabis, Christoph Weber

Increasing shares of electricity generation from renewable energy sources (RES) all over Europe challenge the multi-national electricity power system, especially against the backdrop of the maintenance of security of supply. We therefore propose a novel probabilistic methodology for the assessment of security of supply. While the uncertainty of conventional technologies primarily results from unplanned technical outages of single units, the uncertainty of RES infeed and demand is dominated by fundamental effects, notably weather and societal patterns of production and consumption. A combined approach is used to characterize these uncertainty factors involving quantile regressions and Gaussian copula. This approach allows considering both, conditional multidimensional distributions and spatial correlations between countries. Monte-Carlo simulation in combination with Optimal Power Flow calculations is used to capture the impact of events with low probability of occurrence. Supply shortages identified for single countries in the isolated case may be compensated by imports from neighboring countries. This requires optimal power flow calculations, based according to the European market model on NTCs or PTDFs. Security of supply is evaluated with indicators such as loss of load probability (LOLP) or expected energy not served (EENS). The proposed methodology is applied to a case study comprising the Central West European (CWE) area.

4 - Efficient storage operation and investments: Analytics of the electricity market equilibrium in continuous time

Christoph Weber, Benjamin Böcker

Sustainable energy systems with limited carbon emissions will most likely include high shares of fluctuating renewables, notably from wind power and photovoltaic systems. Today primarily conventional power plants are used to compensate the feed-in fluctuations in order to ensure the availability of electricity in times when needed. Under the foreseen path of massive expansion of renewable energy, this is expected to be no longer sufficient. Hence, storage systems are likely to be part of the efficient technology portfolio in future power systems. This will also impact the price formation in electricity wholesale markets. In continuous time, the optimal operation of storage technologies may be described as a control problem and prices are then given as a costate variable. This control problem is embedded into the longer-term problem of selecting optimal capacities of different thermal and storage technologies. The presentation investigates the properties of the optimal operation problem and the resulting prices as well as the implications for optimal storage dimensioning, including both storage volume and charging/discharging rates. General propositions are derived for the case of multiple storage and multiple conventional generation technologies. Then, the implications are analytically derived for systems with one storage and one generation technology and numerically for multiple technologies.

■ ME-27

Monday, 16:45-18:15 - 302B

Simulating human behaviour

Stream: Behavioural OR
Invited session
Chair: *Duncan Robertson*
Chair: *Young-Jun Son*

1 - SMART cities: Multiple criteria public housing assignment motivated by neurobehavioral simulation

Gordon Dash, Nina Kajiji, S Tiffany Donaldson

Urban cities continually evaluate alternative strategies to reach and sustain a SMART designation. An important policy issue evolves around the efficient assignment of income eligible residents to the supply of public housing apartments. As an OR assignment problem, an efficient solution is one that requires explicit consideration of how assigned families align with targeted prosocial behaviors on a city-wide level. Unlike the uni-objective assignment method, the canonical expression of the subsidized urban housing assignment problem is made complex by excess demand for apartments, anecdotal reports of community-based antisocial behavior and a hierarchy of possibly conflicting social policy objectives. To effectively model this MCDM we extend prior neurobehavioral experiments of animal stress and anxiety to experimentally measure fear, anxiety, reward and movement in alternate rearing environments with and without exposure to stimulant. Based on the neurobehavioral responses of trait-bred Long Evans rats, this research extends prior research in two areas. First, we translate measured brain protein-levels from the rat model to per capita social indicators. Second, utilizing the translated social indicators and other environmental inputs we extend the urban housing assignment optimization problem to a mixed-integer nonlinear goal programming model. The research closes with a discussion of sample solutions SMART city policymakers may find useful for future deliberation.

2 - Neural network analysis of behavioral agent based service channel data

Logan Laite, Karthik Sankaranarayanan

When developing an agent based model for service channel design, the individual decision making process of the agents is a vital part of the simulation. Additionally, due to the nature of agent-based models and the communication networks that exist between agents, the micro/macro-dynamics are heavily linked. To better understand this link, we propose the use of integrated neural networks trained in a supervised learning environment. Training these networks on data collected from human based experiments, and implementing these neural networks into the model will capture the irrational behavior not captured by traditional models, while improving on traditional agent based decision making processes.

3 - A conceptual model of trust behaviour in emergency evacuation: Evidence from Indonesian volcano eruption
Hilya Arini, Tim Bedford, John Quigley

Indonesia, a developing country known as 'The Ring of Fire' in the Pacific, has a large number of disasters that occurred regularly. One of the most prominent ones is the Merapi volcano eruption which has erupted for more than 80 times. In the 2006's eruption, most of the people in Merapi survived from the heavy casualties though they did not evacuate. Their high trust level to the spiritual guardian (i.e. a person appointed by the king to keep people from any danger by speaking to the spirit of Merapi and conducting certain rituals) encouraged their decision not to evacuate. However, the level of trust can change over time. In the 2010's eruption, when the trusted spiritual guardian and the 250 people who trusted him died, the level of trust to spiritual guardians dropped down. Based on this, understanding trust behaviour can be considered important in influencing people decision in emergency evacuation. Thus, this study aims to develop a conceptual model of trust behaviour in emergency evacuation for building Agent Based Modeling and Simulation (ABMS). For this, twenty-one government and non-government participants involved in the Merapi volcano were interviewed. The result of the interview is used as the basis to develop a conceptual model using Modelling Agent System using Institutional Analysis (MAIA). This conceptual model can be utilised to identify the dynamics of trust behaviour and help the actual user of ABMS to understand how the simulation works.

4 - Agent-based models for simulating behavior
Duncan Robertson

We present an overview of how agent-based models can be used to simulate behavior. By reviewing existing agent-based models, we propose a roadmap for the use of the technique on behavioral operational research.

■ ME-28

Monday, 16:45-18:15 - 303A

Radiotherapy optimization

Stream: OR in healthcare
Invited session
Chair: Dionne Aleman

1 - Multicriteria approach for IMRT treatment planning based on fuzzy inference systems
Joana Matos Dias, Humberto Rocha, Brígida da Costa Ferreira, Tiago Ventura, Maria do Carmo Lopes

IMRT (Intensity Modulated Radiation Therapy) is one of the main treatment modalities used for cancer treatment. Treatment plans are defined for each patient based on the medical prescription which comprises a set of constraints defining lower and upper bounds on the radiation dose to be delivered. These constraints should be satisfied in order to guarantee the delivery of a sufficient dose to the volumes to treat and, at the same time, spare all organs at risk. IMRT treatment planning is a multicriteria optimization problem being very difficult to objectively define the concept of optimal solution. There are several conflicting criteria related with the need to proper irradiate the volumes to treat and, at the same time, the necessity to spare organs at risk. Different decision makers can, possibly, choose different treatment plans. We present an automated optimization procedure based on fuzzy inference systems that is able to calculate a set of potential nondominated solutions for IMRT treatment planning. This set of nondominated solutions is obtained by considering each of the delineated structures, one at a time, as being the most important structure in the optimization procedure. All the constraints and weights used in the inner optimization models are dynamically changed by using fuzzy inference systems, allowing the automatic calculation of a set of potential nondominated solutions that comply as most as possible with the medical prescription.

2 - Automation of quality assurance for radiotherapy treatment plans
Hootan Kamran Habibkhani, Dionne Aleman, Chris McIntosh, Tom Purdie

In radiation therapy, a common cancer treatment, treatments must be carefully designed to deliver appropriate dose to targets while avoiding healthy organs. Treatments are generally designed manually by dosimetrists, with some assistance from commercial software. Each treatment plan then undergoes a quality assurance (QA) process, wherein the plan is reviewed by an expert radiation physicist to ensure adherence to clinical guidelines and physical delivery capabilities. If the plan is deemed acceptable, it is delivered to the patient; otherwise, the plan is returned to the dosimetrist for improvement, and the QA process is repeated. QA is time consuming and subject to human error, which may allow substandard or even dangerous treatments to be delivered to patients. We therefore develop an automated machine learning algorithm to identify "good" plans (plans that are similar to historically approved plans) and "bad" plans (plans that are dissimilar to historically approved plans). Good plans are automatically approved for treatment, while bad plans are reviewed by the human expert and returned to the dosimetrist if necessary. To account for the extreme class imbalance in treatment records (only 22% of records in our dataset are bad plans), we develop a supervised extension of projective adaptive resonance theory, called SuPART, which obtains 88% accuracy with only 10 misclassified case on a breast cancer dataset of 83 patients.

3 - Coupling inverse optimization and knowledge based planning
Aaron Babier, Justin Boutilier, Andrea McNiven, Timothy Chan

To automatically generate intensity-modulated radiation therapy plans that match or surpass clinical oropharynx plans, by combining knowledge-based planning (KBP) predictions with an inverse optimization (IO) pipeline. We generalized a prior KBP model that used overlap volume histograms to predict achievable dose volume histograms (DVHs). We applied this method to a dataset of 217 oropharynx patients. The predicted DVHs were input into an IO pipeline that generated treatment plans (KBP plans) via an intermediate step using estimated objective function weights and an inverse planning model. To isolate the effect of the KBP predictions, we also put clinical DVHs through the IO pipeline to produce clinical inversely optimized (CIO) plans. The KBP plans were benchmarked against the CIO plans using DVH differences and clinical planning criteria. Compared to clinical plans, KBP plans consistently achieved lower dose to OARs (5.3Gy median reduction). The KBP plans also satisfied 93% of planning criteria for the high-dose targets, compared to the CIO (86%) and clinical (89%) plans. However, KBP plans satisfied criteria for low-dose targets at a lower rate (38%) compared to the CIO (50%) and clinical (55%) plans. Our automatically generated KBP plans can replicate, and typically improve upon, the dose to OARs and primary target coverage observed in clinical treatment plans for a very large cohort of oropharynx patients.

4 - A novel matheuristic method for the volumetric-modulated arc therapy treatment planning problem
Mehdi Mahnam, Michel Gendreau, Nadia Lahrichi, Louis-Martin Rousseau

Volumetric-Modulated Arc Therapy (VMAT) is a new form of radiation therapy technology with more flexibility on dose delivery. We propose a novel heuristic for the VMAT treatment planning problem in which the gantry speed, dose rate, and aperture shapes are determined simultaneously. Our heuristic is based on column generation; the aperture configuration in the form of partial arcs is modeled in the pricing sub-problem using graph theory and the dose distribution is optimized in the master model. Although a weighted quadratic dose objective function is used in this method, the quality of the treatment plans are evaluated with Dose-Volume Histograms (DVH) in practice. Then, in this heuristic, we also propose an algorithm to automatically adjust weights based on DVH goals in VMAT treatment planning. The efficiency of the algorithm and the treatment quality are evaluated on a benchmark clinical prostate cancer case.

■ ME-29

Monday, 16:45-18:15 - 303B

Military, defense and security applications 3

Stream: Military, defense and security applications
Invited session
Chair: *Ana Novak*
Chair: *Ana Novak*

1 - Scenario based military logistics modelling - Methodological and practical challenges
Brynjar Arnfinnsson

In the absence of major threats to national security after the end of the cold war, the focus of the Norwegian armed forces gradually shifted away from national defense towards international operations. As a consequence, the logistics and combat support elements required for major national joint operations have been neglected and underfinanced during these years. A recent shift back towards a focus on national defense has revitalized the question: How can and should we deploy and sustain our future armed forces in a national joint operation? Based on our work on this subject, we will discuss methodological and practical problems with logistics modeling and analysis as part of a scenario and capability based method.

2 - Workforce analytics for strategic human resources planning
Jillian Henderson, Mira Halbrohr

This presentation will discuss the analytical methodologies and tools used to support evidence-based decision making with regards to DND's civilian workforce, namely: leveraging historical data for use in demographic and trend analyses; and applying occupation flow simulation and forecasting models developed by DGMPRA to inform recruitment, strategic HR planning and policy development. Sample analyses will be presented and include key empirical outcomes such as: the characterization of occupation feeder groups; duration of stay in an occupation as a function of gender and former military status; and internal churn through promotions and lateral movements. The benefits and challenges of applying these approaches in support of civilian HR management in DND will be discussed.

3 - Discrete-event simulation in the maintenance process of Brazilian marine corps armored vehicles
Fabricio Carvalho, Fernando Alexandrino, Edilson Arruda, Glaydston Ribeiro

The Brazilian Marine Corps is a military force that operates in hostile territory and uses armored personnel carrier vehicles, such as General Dynamics European Land Systems/MOWAG PIRANHA IIIC. This paper uses discrete-event simulation models to simulate different scenarios under different demand rates with the aim of reducing total maintenance time, and consequently the number of unavailable armored vehicles. All models consider that mechanics may be unavailable due to other military demands, and spare parts may be lacking due to scarce resources. The aim is to reduce the average total time that each vehicle spends in the maintenance system, thereby reducing the average number of vehicles undergoing repair. To fulfill such an aim, we developed discrete-event simulation models taking into account the specific military issues described above, and implemented them in the ARENA 14 software. The research began with the modeling process (conceptual and computer models). Then verification and validation were performed. The input data was based on 3 years of maintenance report. Various scenarios were simulating with several configurations for preventive and corrective maintenance teams, and the results show that small carefully organized teams may obtain better results than large ones. In addition, a sensitive analysis indicates the point when the maintenance teams must be reformulated.

4 - The optimal supply of trainee pilots using Markov decision processes
Ana Novak

In this project we study the optimisation of the highly constrained and complex pilot training manpower supply for the Royal Australian Navy (RAN). We formulate the optimal manpower supply problem as a Markov Decision Process (MDP) and use value iteration that penalises failure to achieve the required capability. The system's states include the counts of all students and instructors at various locations in the training continuum. Actions are used to select the number of trainees for each course from those available from earlier courses, with the constraint that without an adequate numbers of earlier year graduates the system fails. For a small problem representing a simplified version of the RAN aviation training continuum, this method yields results which significantly outperform an iterative approach using standard Integer Linear Programming. This latter, effectively greedy, approach fails to maintain operational capability for more than just a few epochs. The MDP/DP approach, on the other hand, sustains operational capability, at minimal cost, over a timescale well beyond that required for practical planning purposes. However, for larger problems comparable in size to the full RAN aviation training continuum, the current MDP/DP approach leads to computational difficulties that can be overcome via computational simplifications arising from the specific structure of the MDP, and approximations, to enable a feasible computations yielding close to optimal solutions.

■ ME-30

Monday, 16:45-18:15 - 304A

Forest harvesting planning

Stream: OR in forestry
Invited session
Chair: *Sonia Pacheco Faias*

1 - Comparing full and partial bundling in combinatorial auctions for timber allocation in Quebec
Riadh Azouzi, Marc-André Carle, Mikael Rönnqvist, Sophie D'Amours

The government of Quebec provides 25% of the timber cut in crown forests through sealed-bid one winner auctions. Because they are not allowed to bid for bundles of preferred areas, many companies do not participate in the auctions and thus large volumes of timber remain unsold. The option of bundling forest areas can be one where buyers need to form "full" or "partial" bundles. In "full bundling", a company bids on combinations of stands so that the total volume covers his needs. However, this constraint is relaxed in "partial bundling". It is difficult to tell which configuration is more efficient than the other. This depends on the rules defined by the seller to govern these systems and on the strategies adopted by the companies to meet these rules. Thus, comparisons need to be made. In this work, we propose a framework for analyzing the effectiveness of different bundling systems in maximizing government revenues and enhancing companies' competitiveness. We use actual forest data to simulate different rules and strategies for the allocation of partial and full bundles. Our results suggest that the use of the option of bundling forests areas makes the auction process more beneficial to the majority of stakeholders: Government revenues are increased, and the companies are more likely to obtain the desired volumes and pay less for harvesting and equipment relocations. However, the 'all or nothing' logic of the full bundle auctions is a source of risk.

2 - Forest harvest scheduling with clearcut and core area constraints
Isabel Martins, Joao Pedro Pedroso, Miguel Constantino, Teresa Neto

Many studies regarding environmental concerns in forest harvest scheduling problems deal with constraints on the maximum clearcut size. However, these constraints tend to disperse harvests across the forest and thus to generate a more fragmented landscape. When a forest is fragmented, the amount of edge increases at the expense of the core area. Highly fragmented forests can neither provide the food, cover, nor the reproduction needs of core-dependent species. This study presents a branch-and-bound procedure designed to find good feasible solutions, in a reasonable time, for forest harvest scheduling problems with constraints on maximum clearcut size and minimum core habitat area. The core area is measured by applying the concept of subregions. In each branch of the branch-and-bound tree, a partial solution leads to two children nodes, corresponding to the cases of harvesting or not a given stand in a given period. Pruning is based on constraint violations or unreachable objective values. The approach was tested with forests ranging from some dozens to more than a thousand stands. In general, branch-and-bound was able to quickly find optimal or good solutions, even for medium/large instances.

3 - Estimating the value-creation potential of optimal wood supply plans
Gregory Paradis, Luc LeBel

Current implementation of wood supply optimization models in Quebec, Canada, do not include financial performance indicators. We describe a methodology for compiling a hybrid simulation-optimization model that can be used to estimate the value-creation potential of any subset of species-wise annual allowable cut (AAC) volume. Our model retro-fits financial performance indicators to the optimal solution of the long-term wood supply optimization model, which we link to a network flow optimization model that simulates profit-maximizing fibre consumption behaviour of a network of primary processing facilities. Our methodology uses the official government wood supply models, uses only input data that is readily available to government analytical staff, and can be applied with relative ease to any of the 71 management units in Quebec. To the best of our knowledge, we use the best data currently available. Thus, we present a methodology that produces state-of-the-art value-creation-potential estimates, and could potentially be implemented immediately by government staff in Quebec. We run a number of scenarios on management unit UA 064-51, as an example, and report value-creation potential as a function of the proportion of AAC that is consumed. We show that net value-creation potential of harvesting and consuming the entire AAC is negative.

4 - Competition pattern in young cork oak stands
Sonia Pacheco Faias, Joana Amaral Paulo, Margarida Tome

Cork oak is a Mediterranean species from which the tree bark or cork is extracted and used as raw material. Portugal is responsible for supplying more than 50% of the world cork market. Since, this tree species plays a key role in agroforestry systems the area of cork oak plantations has been increasing in this country. Any contribution to improve silvicultural management will lead to a positive economic value. Thinning is a silvicultural operation that control stand structure over time by reducing tree density. The aim of this study is to understand at which stage of the stand development in young cork oak stands does competition unfold and which type of competition was in place. This will allow determining an optimal schedule for the thinning. For the analysis, data from permanent plots on juvenile stands located across the cork oak Portuguese area were used. This dataset contains tree measurements, with a time interval of at least three years by plot. As a result, it was possible to understand that the current spacing used on cork oak plantations may not lead to tree competition before the 2nd cork extraction. The 1st cork extraction occurs when the tree diameter over bark achieves a legal threshold (around 20 years), but cork quality can only be assessed by the time of the 2nd cork extraction. Thus, it is suggested that the thinning operation could be carried out at the 2nd cork extraction when the tree cork quality can be evaluated.

■ ME-31

Monday, 16:45-18:15 - 304B

Energy system optimization

Stream: Energy economics, environmental management and multicriteria decision making
Invited session
Chair: *Reinaldo Souza*
Chair: *Hans Christian Gils*

1 - Methods to improve computing times in linear optimization energy system models
Hans Christian Gils, Karl-Kien Cao, Manuel Wetzel, Felix Cebulla, Kai von Krbek, Yvonne Scholz, Frieder Borggrefe, Tobias Fichter

Due to the high number of decentralized components, as well as the increasing importance of storage, grid and demand response, energy systems based on renewable energy sources feature a very high complexity. This complexity is reflected in state-of-the-art energy system models, which typically combine a comprehensive representation of energy sectors and technologies with a high spatial and temporal resolution. A high level of detail, however, goes hand in hand with long model solution times. Consequently, measures to reduce model solution times are urgently needed as well as guidelines how to find a reasonable balance between degree of detail and solution time. The BEAM-ME project addresses the need for improved computing power and efficiency in energy systems modelling. With the German Aerospace Center being the principal investigator on the modelling side, the project gathers various partners with complementary expertise in the fields of optimization algorithms, high performance computing and application development. This talk provides an overview and evaluation of the conceptual and technical strategies identified so far to reduce the model solution time of the REMix energy system model. Furthermore, it provides insight in the implementation and assessment of selected speed-up strategies applied to the energy system model REMix. Finally, conclusions from the first project results are drawn, and an outlook on the subsequent works is given.

2 - Feedback of electricity consumption and price
Reinaldo Souza, Fernando Luiz Cyrino Oliveira, Paula Maçaira, Gheisa Esteves, Vanessa Oliveira, Danilo Carmo, Plutarcho Lourenco, Bruno Bastos, Rodrigo Calili, Felipe Silva, Wesley Fagundes

The behavior of electricity consumption in Brazil is of great interest since this variable has a key role as a vector of economic, social development and improvement of the quality of life. The future trends of electricity demand also guide the composition and growth of the electric matrix, as well as its capacity of attendance to the demand of the population. Misconceptions in the planning of this matrix can lead to problems such as shortages in the supply and/or abrupt increase in prices, among others. Situations such as those mentioned cause losses of various natures to the country, generating from inflationary pressures to reduction of economic growth. For planning purposes, it is important to design a tool capable of integrating electricity demand forecasting in the long term with the estimation of hourly demand and the feedback of the electricity price in the short term. In this paper, the annual electricity demand will be modeled through a bottom-up approach, the transformation into an hourly demand will be through a tool of adjustment of the energy load curve that will be inputted into a platform that provides the planning of the expansion of the electric system, which has as output the electricity price. This variable feeds back the bottom-up model, and new rounds are performed on the model until convergence is achieved. It is evident not only the innovative nature of the tool, but also its potential, which serves as support to perform a range of critical analyzes.

3 - Integrated regional electricity planning models: Generation/transmission investments and market-clearing equilibrium
Emre Çelebi

In the deregulated electricity markets, planning and investment decisions of the privately owned generation companies are driven by economic considerations in response to market outcomes. On the other hand, investment decisions for the transmission system are anticipated by the transmission system operator (TSO) who characterizes reliable and secure system operations. Market-clearing models can inform these generation/transmission investors on price signals formed in the competitive market, other generator's behaviors underlying these price signals and the ultimate investment decisions. Clearly, planning and investment in generation/transmission as well as market-clearing equilibrium are interrelated and influenced by a variety of factors including fuel costs, strategic behavior of the generation companies and uncertainties in demand and generation assets. Hence, this paper will introduce integrated regional electricity planning models for generation/transmission investments and market-clearing equilibrium considering combination of these factors. Bi-level programming problems are formed for these integrated models and they are reformulated by using a method for discretely constrained mixed complementarity problems (DC-MCP). The proposed models are demonstrated using a realistic 9-node Turkish electricity market model. These models will be useful in planning generation/transmission investments and analyzing the relations among these investments and the market outcomes.

4 - Valuing demand responsiveness: Using houses as batteries to trade electricity across markets and time
James Corbishley

Increasing demand-side flexibility can have positive impacts on electricity markets. 'Smart' technologies which can automate aggregate consumption patterns are one tool that can be used. The value of demand side flexibility, however, is unknown. This talk investigates the gains of optimising electricity heating demand across time and across markets. I focus on Finnish heating consumption given that domestic electricity heating consumption is two thirds of household consumption. I use a thermodynamic model to track household temperatures and then allow an agent to buy electricity in the day-ahead spot market and then buy or sell in the stochastic within-day market. The agent chooses quantities to buy in the spot market, bid curves to submit to the balancing market, and how to distribute the remaining energy across the fleet of houses. I find that the gains from operating in both markets are relatively small, and sometimes negative for three reasons. Firstly, the stochastic nature of the balancing market results in the agent potentially ending up on the wrong side of the market. Secondly, the agent must commit to spot market purchases up to 36 hours before dispatch. Thirdly, the agent must compensate households for temperature variations. This suggests that the potential for demand responsiveness will be overstated when not considering the impact on those undertaking demand responsiveness, and that seemingly profitable investments may be economically inefficient.

Tuesday, 8:30-10:00

■ TA-01

Tuesday, 8:30-10:00 - 307B

Time constrained routing problems

Stream: Discrete optimization in logistics and transportation
Invited session
Chair: *Jean-François Côté*
Chair: *Manuel Iori*

1 - **The vehicle routing problem with time windows and a fragility constraint**
Guy Desaulniers, Clément Altman, Fausto Errico

We consider a new variant of the vehicle routing problem with time windows where the items (e.g., pallets or containers) delivered by a vehicle are positioned in stacks and cannot be moved along the route except to be delivered. The items are either heavy or light. The fragility constraint forbids stacking a heavy item over a light item. We develop different branch-price-and-cut algorithms to solve this problem. Some of them exploit theoretical results on the feasibility of a route subject to a fragility constraint. Computational results on instances with stacks of a maximum height varying between 2 and 4 will be reported.

2 - **A GVNS heuristic for the traveling salesman problem with time windows - Minimizing completion time**
Khalid Amghar, Jean-François Cordeau, Bernard Gendron

We use a GVNS (General Variable neighborhood search) heuristic for the traveling salesman problem with time windows where the objective is to minimize the completion time. We use efficient methods for checking the feasibility and the profitability of a movement, and for exploring the neighborhoods. The results indicate that our method is very competitive with the state-of-the-art.

3 - **A tabu search heuristic for a multi-attribute technician routing and scheduling problem**
Ines Mathlouthi, Michel Gendreau, Jean-Yves Potvin

We consider a problem motivated from an application for the repair of electronic transaction equipments. In this problem, a number of technicians with different skills must carry out tasks. Then, a route must be built for each technician, starting and ending at his home base location, so as to minimize an objective involving overtime, total traveled distance and total gain over performed tasks. A number of constraints must also be taken into account, like working hours, breaks, multiple time windows for service, as well as availability of spare parts and special parts. The latter characteristic distinguishes our application from others.That is, a task may require, a special part, to be done.We propose a tabu search heuristic to address this problem.The tabu search starts with an initial solution constructed with a greedy insertion heuristic followed by a local descent.Then, this solution is improved using a neighborhood structure obtained by moving or exchanging tasks. The tabu search also includes an adaptive memory that contains a number of solutions visited during the search.When the search stagnates, some of these solutions are combined to provide a new starting solution for the tabu search.The management of this adaptive memory is such that only the best solutions are kept, as measured by their cost and the diversity they bring to the memory.We report results obtained with different instances and we provide a comparison with an exact branch-and-price algorithm.

4 - **Large neighborhood search with constraint programming for the time-dependent vehicle routing problem with synchronization constraints**
Michel Gendreau, Hossein Hojabri, Jean-Yves Potvin, Louis-Martin Rousseau

We consider a variant of the classical Vehicle Routing Problem with Time Windows, in which the routes of two different types of vehicles must be synchronized at some customer locations. We also assume that the travel times of vehicles vary in different regions over various time slots of the working day. Travel times are computed on the basis of time-dependent travel speed profiles, in which speed remains constant over given time intervals, as in the well-known model of Ichoua et al. (2003). This problem is encountered in many practical applications, such as, e.g., the home delivery and installation of large appliances or electronic equipment, and it presents interesting scientific challenges due to the interdependency among the vehicle routes. It has, however, received little attention in the scientific literature. To tackle this problem, we propose a constraint programming-based Adaptive Large Neighborhood Search approach. A global constraint was derived to embed the time dependency in the constraint programming model. This constraint checks the feasibility of modifications to the current solution in an efficient fashion. The proposed approach was tested on instances having between 25 to 200 customers. These instances were derived from the well-known benchmark instances of Solomon (1987) and Homberger and Gehring (1999), while the speed profiles were taken from Ichoua et al. (2003). Extensive computational results will be reported.

■ TA-02

Tuesday, 8:30-10:00 - 308B

New developments in planning of assembly lines

Stream: Design and management of manufacturing systems
Invited session
Chair: *Yossi Bukchin*
Chair: *Olga Battaïa*

1 - **Constraint programming for solving the simple assembly line balancing problem**
Yossi Bukchin

In this research, the constraint programming (CP) approach is applied for the first time for the simple assembly line balancing problem (SALBP). CP is a rich modelling language that enables the formulation of general combinatorial problems and is coupled with a strong set of solution methods that are available through general purpose solvers. The proposed formulation is a conversion of the well-known mixed integer programming (MILP) formulation of SALBP-1 to CP, along with a new set of constraints that helps the CP solver to converge faster. As a generic solution method, we compare its performance with the best known generic MILP formulation and show that it consistently outperforms MILP for medium to large problem instances. A comparison with SALOME, possibly the best custom-made algorithm for solving the SALBP-1, shows that both approaches are capable of efficiently solving problems with up to 100 tasks, with a small advantage to CP. When 1000-task problems are concerned, SALOME provides better performance; however, CP can be used as an efficient heuristic for multiple combinations of problem parameters. Finally, the generality of the CP approach is demonstrated by some simple adaptations of the proposed formulation to other variants of the assembly line balancing problem.

2 - **Balancing mixed-model assembly lines in the footwear industry with a variable neighbourhood descent method**
José Soeiro Ferreira, Parisa Sadeghi, Rui Rebelo

The presentation considers new Mixed-model Assembly Line Balancing Problems in a major footwear company. The company just installed a very flexible automatic transportation system, incorporating various stitching lines. Boxes with components of different models of shoes simultaneously move in the lines, in any direction, stopping at any assigned workstation. Boxes may move between an automatic warehouse and a workstation or between workstations. Consequently, the need to manage the lines and fulfil the variety of client orders. The main goals selected are minimizing the number of workstations and smoothing operators' workload. An optimisation model was developed, but it was impossible to solve real dimension problems. However, that was useful to better understand the situation, to undertake some tests and to validate solutions. After, an approximate method was devised, RPW-VNDbal, based on an integration of the Ranked Positional Weighted (RPW) method (conveniently adapted) and a Variable Neighbourhood Descent (VND) method. The adapted RPW was used to obtain initial feasible solutions, which are then improved by a VND method. Computational tests were undertaken, also based on real data. Simulation was also used to evaluate the solutions. The results obtained with RPW-VNDbal are quite favourable, when compared with some balances executed by the company. Moreover, RPW-VNDbal is easy to use, faster and very convenient to analyse the consequences of any line change.

3 - Resequencing mixed-model assembly lines with restoration to customer orders
Florian Taube, Stefan Minner

We consider a supplier who delivers products to an original equipment manufacturer (OEM) just-in time and just-in-sequence. Production at the supplier is done via a mixed-model assembly line. The time between knowing the OEM sequence and delivering the finished workpieces to the OEM is small. Nonetheless, resequencing for the mixed-model assembly line at the supplier might be advantageous under various objectives such as workload balancing, leveling of materials consumption or color batching. However, if resequencing is done, the effort to restore the original OEM sequence should be small to achieve this in time. We propose a model for optimizing resequencing under the condition that restoring the original sequence is achieved via a first-in-first-out (FIFO) strategy, where workpieces are stored in mix banks at the end of production and only the workpieces at the front of those banks have to be dispatched in order to rebuild the original sequence. The model is a combined assignment or traveling salesman and a vehicle routing problem. We adapt the load balancing, material leveling, and color batching problem from sequencing literature to our formulation and present numerical results derived from a controlled testbed, which show that huge savings (> 50% on average), compared to producing the OEM sequence as-is, are made. Furthermore, a limited look-ahead approach leads to good solutions in just a few number of seconds, even for large scale problems.

4 - Operations research approaches to mitigate ergonomic risks: Case of paced assembly lines
Olga Battaïa, Dmitry Arkhipov, Alena Otto

Factors such as repetitiveness of work, required application of forces, handling of heavy loads, and awkward, static postures expose assembly line workers to risks of musculoskeletal disorders. While addressing the problem of high ergonomic risks, most companies take the workload of workers as given and look for introducing specialized equipment and support tools. However, such policies have limited impact in many cases. Therefore, it is important to lower ergonomic risks by incorporating ergonomics aspects in the planning of the workload of workers. In this talk, we review the available modelling approaches considering ergonomics in operational planning of paced assembly lines and outline future research directions. We also present the job rotation scheduling problem as an example of such problem, report on its complexity and share the first computational results on the developed solution methods.

■ TA-03
Tuesday, 8:30-10:00 - 200AB

Keynote speaker: Roman Slowinski

Stream: Keynote sessions
Keynote session
Chair: Theodor Stewart

1 - Preference learning through robust ordinal regression
Roman Slowinski

Identification of Decision Maker's (DM's) preferences is crucial for decision aiding. We present a constructive preference learning methodology, called Robust Ordinal Regression, for Multiple Criteria Decision Aiding. It is known that the dominance relation established in the set of alternatives evaluated on multiple criteria is the only objective information that comes from the formulation of a multiple criteria decision problem (ordinal classification, or ranking, or choice - with multiobjective optimization being a particular case). While it permits to eliminate many irrelevant (i.e., dominated) alternatives, it does not compare completely all of them, resulting in a situation where many alternatives remain incomparable. This situation may be addressed by taking into account preferences of the DM. Therefore, decision aiding methods require some preference information elicited from a DM or a group of DMs. This information is used to build more or less explicit preference model, which is then applied on a non-dominated set of alternatives to arrive at a recommendation presented to the DM. In practical decision aiding, the process composed of preference elicitation, preference modeling, and DM's analysis of a recommendation, loops until the DM accepts the recommendation or decides to change the problem setting. Such an interactive process is called constructive preference learning. We will focus on processing DM's preference information concerning multiple criteria ranking and choice problems. This information has the form of pairwise comparisons of selected alternatives, and/or comparisons of intensities of preference between pairs of some alternatives. Research indicates that such preference elicitation requires less cognitive effort from the DM than direct assessment of preference model parameters (like criteria weights, comparison thresholds, or trade-offs between conflicting criteria). We will describe how to construct from this input information a preference model being a utility function or an outranking relation, via Robust Ordinal Regression (ROR). An important feature of ROR is identification and use of all instances of the preference model that are compatible with the input preference information - this permits to draw robust conclusions in terms of necessary and possible relations in the set of considered alternatives. The methodology will be presented along with some examples of their application.

■ TA-04
Tuesday, 8:30-10:00 - 202

Healthcare and knowledge management analytics

Stream: Healthcare and knowledge analytics
Invited session
Chair: A. D. Amar

1 - Estimating causality using balance optimization subset selection
Sheldon Jacobson, Hee Youn Kwon, Jason Sauppe

Controlling estimator bias is a challenge when assessing causality, which occurs when estimating a treatment effect from observational data in medical studies. This paper focuses on one method of estimation, Balance Optimization Subset Selection (BOSS). We investigate cases that may generate bias in the context of BOSS, and discuss how to mitigate it. While doing so, a balance hierarchy is created, which leads to particular imbalance measure that correspond to particular functional forms of the responses. New imbalance measures drawn from the Cramer-von Mises test statistic are also introduced. The cases of insufficient data and suboptimality that can arise in causal analysis with BOSS are discussed.

2 - An OR and MIC-based data analysis: Does short-term air pollution affect the outpatient visits for acute exacerbation of COPD?
Li Luo, Yong Lei, Zhilin Yong

COPD is a common chronic disease with a high mortality rate in the world.Previous studies have shown that air pollution is closely related to the mortality of COPD. However, few studies have examined the association between short-term air pollution and the outpatient visits of COPD. This study is to analyze short-term air pollution and corresponding changes in outpatient visits of COPD. We select the outpatient data of HIS system of a hospital from 2014 to 2015, and the matching air quality data in Chengdu, China.Odds Ratio (OR) risk factors assessment method was used to evaluate the effect of air pollution in a short time (3 to 14 days) on the average daily outpatient visits in the next 7 days. Then, we used the Maximal Information Coefficient (MIC) to evaluate the explanatory degree of air pollution in a short-term for the corresponding 7-day average daily outpatient visits. The results shows that Lag8_7_151 has the highest risk of high daily outpatient visits, with OR of 4.263 (0.255 to 71.271, CI = 95%), but a significance test> 0.05. The MIC of the independent variable OutVisits (daily outpatient visits) and the dependent variable Mean_Lag14 is 0.255, while the maximum MIC of the independent variable Outrank (a 0-1 variable, namely the grade of outpatient visits) and the dependent variable Lag13_4_151 is less than 0.01. The results shows that short-term air pollution is not, directly leading to the outpatient visits of COPD increased.

3 - Combining Domain Knowledge with Interpretable Machine Learning in Industrial Chemical processes
Ahmed Ragab, Hakim Ghezzaz, Mohamed El Koujok, Mouloud Amazouz, Soumaya Yacout

Experts in industrial chemical processes build repositories within their organizations, based on domain knowledge (DK) in order to analyse abnormal and faulty situations and to make appropriate decisions. Such repositories typically contain the fault tree analysis (FTA) in addition to descriptions of abnormal situations and their corrective actions. The major limitation of FTA is that it requires detailed system knowledge that involves high level of human efforts. Machine learning (ML) techniques exploit the historical databases, in order to discover hidden phenomena that are too subtle for humans to detect. This presentation proposes an innovative methodology that combines DK with ML. The objective is to allow automatic enriching and updating of existing DK, in order to achieve fault detection and diagnosis (FDD) in chemical processes. The methodology uses a predictive/descriptive ML technique called logical analysis of data (LAD). It is based on a set of interpretable patterns extracted by solving mixed integer linear program (MILP). The proposed methodology is demonstrated using a fault tree constructed for a pulp mill process. The tree was updated successfully with minimal efforts needed from the experts.

4 - Data science for knowledge generation in human-computer interaction
Guillermo Molero-Castillo, Alejandro Velázquez Mena

In this work, a combination of two areas is proposed that offer ideal conditions to approach new challenges with the objective of creating new algorithms and interaction systems for the discovery of novel knowledge through data analysis. Data that comes from sensors, mobile devices, social networks, images, digital videos, purchase records, banking transactions, mobile and ubiquitous computing, among others. Making sense of these data remains a fundamental challenge, so one of the great challenges is the analysis of these complex data volumes, which require new, efficient and easy to use solutions for their manipulation and understanding. In this sense, the synergistic combination of processes, approaches, and methods of two originally separated areas, data science, and human- computer interaction (DC-HCI), has an impact not only on academia but on society, which could be a knowledge field important in the science and technology. The purpose is to promote research for the development of new algorithms and user-centered interactive systems, with the main objective of improving human interaction, representation, and visualization of new data patterns of valid and potentially useful, as support in decision-making. In this case, the starting point is pattern recognition through visual data analysis.

■ TA-05

Tuesday, 8:30-10:00 - 203

Stochastic model 2

Stream: Stochastic modeling and simulation in engineering, management and science
Invited session
Chair: Yasushi Masuda

1 - Sustainable agricultural supply chain management considering weather derivative and contract farming
Takashi Hasuike

This paper considers a sustainable agricultural supply chain management to find the optimal matching between farmers and retailers with the contract based on their higher satisfactions of the total return. It is important to construct the food distribution system to hold the win-win relationship among all stakeholders in terms of sustainability. Furthermore, it is also important to find the optimal matching and trading volume between farmers and retailers to maximize the total profit, because the total volume of a product at a specific farmer should be sold out at a specific retailer to need it. Of course, there is uncertainty of production volume due to weather and soil conditions. If the production volume at each farmer in one time slot is all shipped to the retailer, the retailer has some risks such as shortage costs and discarding costs. Therefore, in this paper, the mathematical model of agricultural supply chain management with weather derivative to avoid the above-mentioned risks is formulated. In order to solve the proposed problem, the efficient algorithm to obtain these optimal solutions is also developed.

2 - Applied real option valuation method using simulation and exercise boundary fitting
Yuri Lawryshyn, Matt Davison

Real option analysis is recognized as a superior method to quantify the value of real-world investment opportunities where managerial flexibility can influence their worth, as compared to standard discounted cash-flow methods typically used in industry. However, realistic models that try to account for a number of risk factors can be mathematically complex, and in situations where many future outcomes are possible, many layers of analysis may be required. The focus of this research is the development of a real options valuation methodology geared towards practical use. A key innovation of the methodology to be presented is the idea of fitting optimal decision making boundaries to optimize the expected value, based on Monte Carlo simulated stochastic processes that represent important uncertain factors. First, we show how the methodology can be used to value a simple Bermudan put option and discuss convergence and accuracy issues. Next, we apply the methodology to a real options optimal build / abandon problem for a single stochastic factor. Then, we extend the methodology to a two factor build / abandon case study to value a greenfield mining operation.

3 - Simulation-based assortment optimization
Tien Mai

Our work concerns the assortment optimization problem, which refers to select a subset from an entire set of items that maximizes the expected revenue in the presence of the substitution behavior of consumers specified by a choice model. This is an important problem that arises in many practical applications such as retailing, online advertising, and social security. We propose a simulation-based solution under the discrete choice framework. More precisely, we propose to use the multinomial logit to model the behavior of customers, and formulate a sample average approximation of the assortment optimization problem. This results in a mixed-integer optimization (MIO) model, which is flexible and can easily accommodate with different types of business constraints. We report numerical results using a real transaction data set showing the flexibility and tractability of our simulation-based approach.

4 - Routing control for a system with parallel stations and homogeneous customers by priority pass
Yasushi Masuda, Akira Tsuji

We examine the effect of priority passes on the performance of a congested system with a finite number of parallel stations and a homogenous population of customers. A state of the system is described by a vector of probabilities, one for each station. The probability of a station is the probability for each customer in the population to visit station j. Each customer strives to maximize the benefit from visiting a station minus the time cost of spending in stations, subject to a constraint on the total amount of time spent in the system. The service time of each station is assumed to be an increasing function of the probability of each customer visiting it. We prove that this model has a unique equilibrium. We generalize this model assuming that a fixed number of priority passes is handed out to each customer. A state of the system is described by two probability vectors, for visiting each station with and without priority pass, respectively. We show that if the time constraint is not binding, then the equilibria in the model with priority passes are not worse than the equilibrium in the model with priority passes in terms of social welfare. We further provide a sufficient condition under which the model with the priority pass strictly outperforms the model without the priority pass. We provide numerical examples as well.

■ TA-06

Tuesday, 8:30-10:00 - 204A

CORS practice prize

Stream: CORS practice prize
Invited session
Chair: *Mikael Rönnqvist*
Chair: *Bernard Gendron*
Chair: *Mustapha Ouhimmou*
Chair: *Fredrik Odegaard*

1 - A two phase algorithm for a real-life 3D container loading problem
Philippe Grangier, Marc Brisson, Michel Gendreau, Fabien Lehuédé, Louis-Martin Rousseau, John Ye

We present a real-life 3D container loading problem of agricultural tires. There exist many references of agricultural tires ranging from relatively small diameters (around 50 centimeters) to very large diameters (up to 2 meters). As such, each shipment usually contains a heterogeneous set of tires and shipments differ from one to another. Finding a valid loading plan for a given set of tires is a challenging problem that differs from the vast majority of packing problems in the literature as (1) it deals cylindrical shapes (which make many classical strategies for rectangular boxes not applicable), (2) it integrates many stability/safety restriction constraints. We propose a two-phase method that group tires into templates using a MIP and then locate these templates with a custom recursive dynamic programming method. This project was done in collaboration with JDA Labs the innovation center of JDA Software. As such, the presentation will highlight how the proposed method fits into the transportation solution of JDA Software, as well as how it is being used in a research project for loading with Augmented Reality.

2 - Discrete event simulation model for planning level 2 "step-down" bed needs using NEMS
Felipe Rodrigues, Greg Zaric, David Stanford

In highly congested hospitals it may be common for patients to overstay at Intensive Care Units (ICU) due to blockages and imbalances in capacity. This is inadequate clinically, as patients occupy a service they no longer need; operationally, as it disrupts flow from upstream units; and financially as ICU beds are more expensive than ward beds. Step-down beds, also known as "Level 2" beds, have become an increasingly popular and less expensive alternative to ICU beds to deal with this issue. Using data from London Health Sciences Centre's patient flow management database, we developed a discrete event simulation model that estimates "Level 2" bed needs for its University Hospital campus. The model innovates by simulating the entirety of the hospital's inpatient flow and most importantly, the ICU's daily stochastic flows based on a nursing workload scoring metric called "Nine Equivalents of Nursing Manpower Use Score" (NEMS). We show that with a mix of reallocation of beds and a small net increase in capacity, throughput is maximized and off-service can be reduced by almost 60%. In terms of ICU patient flow, length-of-stay at the Medical Surgical Intensive Care Unit (MSICU) can be reduced by 63% while patient-day costs drop 18%, representing a potential savings of $9.5 million/year.

3 - Applying OR to the gamification of skiing at Whistler-Blackcomb
John Lyons, Peter Bell, Mehmet Begen

Whistler-Blackcomb is North America's largest alpine ski resort. It implemented in Dec 2015 a system of radio-frequency identification (RFID) lift passes and sensor-gates across its network of 24 lift systems. The ability to track skiers forms the basis of a marketing web portal called 'WB+', through which skiers can view personal statistics, 'leader-boards' and related news and interest stories. Some describe it as a 'gamification' of skiing. A particular challenge called 'Mega Day' requires a skier to ride every lift on both Whistler and Blackcomb mountains in a single day, achieved in fewer than 0.05% skier-days since implementation. It demands a well-planned and executed route, subject to varying time windows. It shares features with various routing problems, but includes several unique ones. We modeled it as an MIP, using real data from Whistler-Blackcomb. While the optimal solution is somewhat dependent on individual skier characteristics, our model construction, experimentation and analysis of historical data provided a number of valuable insights to the WB+ team, and in turn a novel and interesting context to discuss route optimization concepts and methods.

■ TA-07

Tuesday, 8:30-10:00 - 204B

Vehicle routing applications

Stream: Vehicle routing
Invited session
Chair: *William Guerrero*

1 - A decomposition-based approach for the coordinated vehicle routing problem
Andrea Arias, Ricardo Gatica, Timothy Matis

We address a variant of the Vehicle Routing Problem in that there is a vehicle of major capacity (e.g. a truck) for which a minimum-cost tour is determined over a subset of clients, such that all the clients are served either by the truck or by a minor vehicle (e.g. an Unmanned Aerial Vehicle). The clients not visited by the major vehicle are assigned to be visited by a minor vehicle that is launched from the major vehicle while the last one is serving a client. It is assumed that the major vehicle continues to visit subsequent clients in its path while the minor vehicle is visiting a client, but the minor vehicle can visit only one client and then it must return to meet the major vehicle at some later point on its path, to be reloaded/recharged for the next launching. We propose a decomposition-based approach for the problem, by solving two integer programs (IP) in sequence. The first IP determines the minimum-cost covering tour for the major vehicle, and the second IP assigns the clients to be visited by the minor vehicle to the major vehicle's path obtained from the first IP. Applications of this problem are found in logistics (last-mile delivery), in the military (border patrolling and surveillance), to mention a few.

2 - Air cargo rescheduling for demand fluctuations considering transshipments
Felipe Delgado, Cristobal Sirhan, Homero Larrain

Demand for air cargo transportation is very difficult to forecast due to its high volatility. This can be explained by the following factors: i) there is a reduced number of clients who transport large volumes; ii) orders are usually placed on relatively short notice; iii) cargo booked to travel often arrives partially, past its deadline, or in the last minute; and iv) there are no penalties in place for clients cancelling an order. This uncertainty can lead to significant operative inefficiencies, generating losses to the airline. In this work we propose and discuss a model for re-optimizing aircraft itineraries and order routing, considering the last-minute demand realizations. This model, which admits transshipments, takes into account the costs involved in changing the itineraries. We propose and model three different ways to evaluate this particular cost, as a function of the additional number of i) crews; ii) trips between airports; and iii) trips between airport by aircraft. Our model was tested using real-life data provided by our partner in the industry on a network of 14 airports and a planning horizon of three days. Three different demand scenarios were constructed, with different disruption levels. Our experiments show the applicability of our methodology, which yield an increase in Load Factors compared to applying the original schedule to the disrupted scenario. Transshipments shows to be beneficial and grow as the level disruption increases.

3 - The technician allocation and routing problem for offshore wind farms
Albert Schrotenboer, Michiel uit het Broek, Bolor Jargalsaikhan, Kees Jan Roodbergen

The total number of offshore wind farms is expected to increase in the coming decades. This may lead to a new scenario in which a single maintenance provider is responsible for maintaining multiple wind farms. Rather than operating each wind farm in isolation from the other wind farms, we look into a flexible deployment of differently skilled technicians between multiple wind farms to increase the efficiency of the short-term maintenance planning. The Technician Allocation and Routing Problem for Offshore Wind Farms therefore asks to jointly determine the allocation of differently skilled technicians to multiple wind farms and the accompanying daily vessel routes to perform the maintenance activities. This problem can be seen as a variant of the well-known pickup and delivery problem. We develop a Variable Neighbourhood Search (VNS) to solve this problem. The VNS achieves high quality solutions (and often optimal solutions) on benchmark instances from the literature with a fixed allocation of technicians to wind farms. In addition, it is shown that in our general setting the flexibility of the daily planning is increased and that the overall costs are reduced.

4 - Bilevel optimization applied to routing problems on healthcare logistics
William Guerrero, Henry leal Moreno, Angélica Sarmiento Lepesqueur

In order to model mathematically the interaction between decisions taking in account hierarchical levels, Bi-level optimization models are studied in the literature. We propose a mathematical formulation to model a hospital shuttle service for a set of frequent dialysis patients where some of them have the choice to book or not the shuttle service. The hospital aims to maximize its profits by collecting as many patients as possible with minimum routing cost, whereas the patients minimize their transportation costs considering possible alternative transportation modes. The problem is addressed through different methods: First, a bi-level programming model is presented, where the hospital is the leader, deciding on the route of a single vehicle, and the patients are the followers, deciding whether or not to be included in the route. Then, a mathematical transformation to an equivalent integer programming model with a single level is proposed, aiming to improve the time to compute the optimal solution. Finally, a hybrid method combining heuristics and integer programming is proposed in order to find high quality solutions. The developed models have shown a more accurate modeling of the decision making process where the decision of the patients have an influence on the routing decisions, and the proposed solutions methods show competitive performance. The proposed model can be further extended to model pricing decisions.

■ TA-08

Tuesday, 8:30-10:00 - 205A

Pricing problems

Stream: Revenue management and pricing
Invited session
Chair: S. Emre Alptekin

1 - A bilevel modelling approach to service network design and pricing: Application to intermodal transportation
Christine Tawfik, Sabine Limbourg

Owing to its ecological and economic potentials, intermodal freight transportation has drawn a wide interest in the scientific and political community. Nevertheless, it remains strongly challenged in the EU market, failing to attract the desired customer levels, with vital research questions remaining overlooked. In this work, we examine the intrinsically related problems of designing freight carrying services and determining their associated prices as observed by the shipper firms, in the context of intermodal networks. More specifically, a path-based bilevel model is proposed for a medium-term planning horizon. At the upper level, in the quest of profit maximization, an intermodal operator jointly selects the frequencies and prices of his services, whilst, at the lower level, the shippers optimally react by deciding on their demand volumes to send over the intermodal itineraries and an always available all-road alternative. Frequency delay constraints are considered as well, in order to capture the impact of the service reliability on the market penetration. Finally, to increase the realism of our study, we integrate behavioral concepts in the expression of the lower level as a logistics costs minimization problem. In particular, a random utility model is adapted for this purpose, based on results coming from specially designated revealed preference exercises. Exact tests are invoked on real-world instances to demonstrate the feasibility of the presented approaches.

2 - A tri-level programming approach for discount coordination under price-sensitive demand
Ginger Ke, James Bookbinder

Quantity discounts have been broadly examined in decisions on the sale or purchase of goods. The analysis of coordinating the discount decisions for the retailer (buyer), the wholesaler (supplier), and the public transportation service provider (LTL carrier), however, is still in its infancy. In this paper, we develop a tri-level programming approach to coordinate the three supply chain members' decisions on discount policies, when the demand is sensitive to the change in price. Both decentralized and centralized scenarios are examined, and a heuristic algorithm is presented to assist the three parties in establishing their discount schemes in a decentralized environment. Through a series of comprehensive numerical experiments based on the linear demand, we show that the price-sensitivity is a key motivation, for all parties, especially the carrier, to offer discounts. Specifically for the wholesale quantity discount, the data analyses also illustrate the different purposes and corresponding structures for the decentralized and centralized cases. For the former case, the discount is quantity-based, which encourages the buyer to increase the quantity for each order; while for the later case, the discount is volume-based, which is used to boost the annual demand. The significant improvements to each party and to the entire supply chain resulting from the discount coordination are also demonstrated under various situations.

3 - Revenue management in the energy field
Luce Brotcorne, Sébastien Lepaul, Léonard von Niederhäusern

Pricing models for demand side management methods are traditionally used to control electricity demand which became quite irregular recently and resulted in inefficiency in supply. In this work, we propose bilevel pricing models to explore the relationship between energy suppliers and customers who are connected to a smart grid. The smart grid technology allows customers to keep track of hourly prices and shift their demand accordingly, and allows the provider to observe the actual demand response to its pricing strategy. Moreover, we assume that the smart grid optimizes the usage of a renewable energy generation source and a storage capacity.

4 - A data pricing framework for internet of things solutions
S. Emre Alptekin, Gülfem Isiklar Alptekin

The Internet of Things (IoT) is a popular term used to define an ecosystem of "smart, connected objects", which interact with its users to enhance their experience and contribute to the quality of their lives. The basic element of this interaction is the data produced as a byproduct, which is fed into the system once again to improve the product/service. The extracted useful information packaged as a value-added service creates a new marketplace for service providers. However, effective solutions require the integration of different data sources and the solution of connectivity related issues. Hence in this work, we propose an intelligent framework for effectively managing IoT resources and also pricing the services depending on the demand and quality characteristics in a competitive market environment. Here, the main objective is to persuade the customers to be part of the system by using/sharing data. Our proposed approach is based on the "smart data pricing" methodology, which identifies users' utilities, offers users' right economic incentives and at the same time manages network congestion particularly in high demand periods. A non-cooperative game model using Nash equilibrium is introduced to analyze the behavior of the service providers and their prospective customers and optimize the respective utility functions.

■ TA-09

Tuesday, 8:30-10:00 - 205B

IFORS: Distinguished lecturer retrospective

Stream: IFORS sessions
Panel session
Chair: Nelson Maculan

1 - IFORS: Distinguished lecturer retrospective
Silvano Martello, Michael Florian, Andrés Weintraub

Past IFORS Distinguished Lecturers will provide a summary of their IDL lecture and discuss how their respective fields have moved forward since their lecture.

■ TA-10

Tuesday, 8:30-10:00 - 205C

Production management and operations management

Stream: Production management, supply chain management (contributed)
Contributed session
Chair: Amy H. I. Lee

1 - The refined proportionality constants of hand dimensions
Ching-Hua Lin, Sheng-Hung Lo

To improve the process of production, ergonomics and work methods is one of the important components of job design. Many ergonomic investigations applied hand dimension data to study grasping or hand tools design. However, most anthropometric databases include only basic dimension of hands, such as hand length or hand width. Specialized hand anthropometric databases are rare; instead, many non-representative small scaled data of hand dimensions have been measured. Proportionality constants, e.g. the mean ratio of arm length to stature height, have been extensively applied to derive more detailed measures of interest from a basic measure. Yet proportions of detailed hand segment dimensions are rare and the results of this approach are inaccurate. This study sampled 400 hands representative of Taiwan civilian population and measured detailed hand segment dimensions by 3D laser scan technologies. The ratios of all the dimensions to hand length were calculated for all samples. And then the results of factor analysis grouped all the dimension ratio variances into four factors. The candidate factors were tested by analysis of variance. Finally, all the hands were stratified by the chosen factors and mean proportionality constants were provided for each stratum to propose an improvement tool for the relevant applications.

2 - A capacity planning model for stockers in 300mm wafer fabrication factory
Ying Mei Tu

Automatic Material Handling System (AMHS) is becoming more important in 300 mm wafer fabrication factories. Effective and efficient design and control of AMHS has become more critical particularly in capacity planning of stockers. It will be extravagant in the space of clean room if the capacity of stockers is surplus. Nevertheless, when the capacity of stockers is insufficient, the production activities will be a chaos. Therefore, how to determine an adequate capacity level of each stocker to keep the production activities smooth is a key factor in 300mm fab. In this study a capacity determination model of stocker is proposed. There are two portions, IS (In Storage) and OS (Out Storage), included in each stocker. In Storage is to store the lots to wait for processing by the equipment within it's own bay. Out Storage is the temporary storage to keep the lots which wait for OHS (Overhead Hoist System) to send to the stocker in other bay. GI/G/m queuing network is applied to calculate the capacity of IS. Besides, the equipment behaviors and confidence level will be taken into account to increase the estimation accuracy of capacity requirement. Regarding to OS, due to high stability of OHS, a single and simple GI/G/m queuing model is established to estimate the queue length waiting for OHS. Finally, each stocker capacity can be determined as the combination of the capacity of IS and OS.

3 - A supplier evaluation model for the food industry
Amy H. I. Lee, He-Yau Kang

Food safety incidents occur frequently in many countries, especially in the developing countries. Food safety is a growing public health concern because foodborne diseases and food safety threats may cause substantial costs to individuals, the food industry and the economy. Due to these endless food safety scandals, firms in the food industry need to reconsider their outsourcing decisions. Food firms need to know how to evaluate and select the suppliers, not only based on the cost, but also the food safety, the quality of the materials and the credibility of the suppliers, etc. A comprehensive model, by integrating the benefits, opportunities, costs and risks (BOCR) concept, the interpretive structural modeling (ISM), the analytic network process (ANP), and the fuzzy set theory, is constructed for evaluating suppliers. The BOCR concept is applied first to list the evaluation factors under the four merits, and the ISM is adopted next to understand the interrelationships among the evaluation factors and to construct an evaluation network. The ANP is then used to evaluate the suppliers under the network. Because of the uncertain nature of the problem, the fuzzy set theory is used in the model. Finally, a case study of a food manufacturer in evaluating and ranking suppliers is presented to examine the practicality of the proposed model. By applying the model, decision makers can evaluate the expected performance of each supplier by considering various important factors.

4 - An integrated replenishment model for the bike industry
He-Yau Kang, Amy H. I. Lee, Wan-Yu Wu

After more than forty years of development, the bike industry in Taiwan has become number one in the world, with several well-known world-leading international brands. The competitiveness of the bike industry is due to the advantages of cost, quality, flexibility, expertise in manufacturing technology, and a complete supply chain. How to manufacture bikes that customers demand with a lower cost and higher quality is important for manufacturers to maintain their competitive edges and to earn a good share of profit in the long run. In devising an appropriate supply chain decision making policy, a production manager needs to consider multiple suppliers, transportation batch and quantity discounts. In this paper, a mixed integer linear programming (MILP) model is constructed first. The objective is to minimize total costs, which include ordering cost, purchase cost, transportation cost, production cost, holding cost and shortage cost. Next, enhanced genetic algorithm (EGA) is applied to solve a complicated problem, which may be too difficult to be solved by the MILP. This is due to the attribute of the EGA to find near optimal solutions in a short computational time. Since the EGA model can be very effective in searching for solutions, it can be very useful for inventory replenishment decisions in real practice. Finally, a case study of a bike manufacturer is presented to examine the practicality of the models.

■ TA-11

Tuesday, 8:30-10:00 - 206A

Traffic flow theory and control problems

Stream: Traffic flow theory and control
Invited session
Chair: Bilal Farooq

1 - An optimization approach for full road flow observability in a traffic network considering the measurement error
Mostafa Salari, Lina Kattan

One common method for traffic monitoring is to use traffic sensors to monitor traffic flows on a road or a route. Regarding a network topology, there is no need to install sensors on every single road or intersection to observe the flows of all roads/routes in that network,i.e. full flow observability, but by putting sensors on some certain roads or intersections in the network, the flows of all roads/routes can be either directly observed or indirectly inferred using the information obtained from the observed flows. Moreover, the sensors measurements are subject to errors. Sensors accuracy differs depending on their employed technology. In general, the more expensive the sensors are, the more accurately they measure the traffic. The aim of this study is to assist traffic managers in placing the affordable types of sensors in a network to minimize the total sensors measurement errors while meeting both budget constraint and full road/route flow observability. The road flow observability is chosen over the route flow in this study to avoid the route enumeration problem. The objective function defined for the proposed model aims to minimize the total measurement errors. The Monte Carlo simulation is then applied to consider the randomness of the measurement errors in finding the optimum location set of sensors. Eventually, the concept of backup sensors is developed to maintain the full road flow observability regarding the possibility of sensors failures in recording the flows.

2 - Development of Variable Speed Limit System to improve travel time
Nadia Moshahedi, Lina Kattan

Variable Speed Limit (VSL) is an Intelligent Transportation System solution that enables dynamic changing of speed limit in an attempt to improve safety and throughput. Performance of these systems is highly influenced by the speed limit implemented at each time step of control horizon. Previous studies failed to use a proper optimization method to find the global optimum solution for their VSL models. This significantly affect the conclusion they made about efficacy of VSL systems designed to improve travel time. In this work, we develop a Model Predictive Control (MPC) VSL model to improve total travel time using rolling horizon approach. To predict the traffic state at each time step, the second-order traffic flow model METANET is adopted. Soft and hard constraints are set to constrain the change in speed over time and space. The objective function is set to minimize the total travel time of the system, while penalizing more than limit increase in speed limit over time and space. The developed model is solved using Sequential Quadratic Programming (SQP) optimization method. Simulated Annealing (SA) is utilized to find the initial solution. Pairing SQP and SA together makes finding the global minimum possible. The developed VSL model is expected to elevate mobility in a hypothetical one-lane freeway with downstream bottleneck.

3 - Large-scale pedestrian movement analysis using a network of Wi-Fi sensors
Bilal Farooq, Alexandra Beaulieu

Automated data collection on the movement and activities of pedestrian is a challenging problem. Pedestrian data collection methods are currently mostly limited to manual counts, video processing and indoor testing. These methods are costly, time consuming and only work on a small scale. In a previous work, we developed a network of cheap sensors that can perform larger scale data collection of pedestrian movements using WiFi signals emitted by WiFi-enabled devices (such as smartphones). The devices are deployed during an entire summer (4 months period) on a pedestrianized street spanning 14 intersections. This data is then processed to produce indicators describing the pedestrians' behaviours, such as time spent, pedestrian density variations through time, flow of pedestrians and the tracking of trajectories and destinations over time. The use of street-level land usage data allows further conclusions to be made about the reasons for these behaviours. The indicators developed, in addition to facility usage information, are then used to develop and estimate a dynamic next location choice model. It can forecast the next location, including the exit, any individual pedestrian choses, conditioned upon its previous and current locations. The model can subsequently be used to predict future events in similar places, and help with the planning, promotion and optimization of such events.

4 - On the origins of mathematical modeling of pedestrian dynamics
Mohcine Chraibi

A microscopic model that considers the movement of pedestrians in a 2D-space was proposed by Hirai and Tarui in 1975. In their seminal work, the authors investigated several aspects of hu- man's behavioral motion. On one side, they considered the movement of pedestrians on the "operative level". Here, the model can be considered as the first known force-based model for pedestrian movement. On the other side, the model investigates different aspects of the "tactical level" of human behavior, e.g. group behavior and the influence of guiding signs on agent's way-finding - aspects which recently caught the intention of the community of pedestrian dynamics with several emerging studies. Hirai and Tarui showed that their model exhibits, to some extend, realistic evacuation behavior in a simplified train station. However, although the model is promising, it was not elaborated sufficiently whether in the above mentioned paper nor later on in the literature. In this work, we explore the abilities of this model with respect to recent published insights on the operational level e.g. by comparing the Fundamental Diagram in different scenarios as well as on the tactical level (routing behavior). Furthermore, we propose a modification of model in a way to reproduce previous experimental studies.

■ TA-12

Tuesday, 8:30-10:00 - 206B

Financial mathematics 3

Stream: Financial mathematics and OR
Invited session
Chair: *Gerhard-Wilhelm Weber*
Chair: *Qi Wu*

1 - A geometrical approach to forecast burst-time of stock market bubbles
Efsun Kürüm, Gerhard-Wilhelm Weber, Cem Iyigün

In order to avoid destructive results of financial bubbles that affect the entire economy, it is important to develop an early-warning signaling. By using optimization-supported tools, we introduce a new method for an early-warning signaling, which approaches the bubble concept geometrically by determining and evaluating ellipsoids. We generate a volume-based index via minimum-volume covering ellipsoid clustering method, and to visualize these ellipsoids, we utilize Radon transform from the theory of the Inverse Problems. The analyses were conducted for US, Japan and China stock markets, also fitted and simulated data were used to observe the performance of our method. For all real, fitted and simulated data, we have found that when the bubble-burst time approaches, the volumes of the ellipsoids gradually decrease and, correspondingly, the figures obtained by Radon transform become more brilliant, i.e., more strongly warning.

2 - Portfolio selection with unfixed investment timings
Chunhui Xu, Yanli Huo, Takayuki Shiina

Portfolio selection problems have been studied under the assumption that investment timings are fixed, which is not true in many real situations. Most investors can be flexible about investments timings, many investors even expect a suggestion about investments timings, however, current investment theories like the modern portfolio theory can not give suggestions for investment timings. This talk is to introduce our study on portfolio selection with unfixed investment timings but the investment term is within a bounded interval. We take the terminating time of an investment term as a decision variable, which will make our models different essentially with that in the modern portfolio theory, our models can provide suggestions about investment fund allocation and investment timings. Since both risk and return are related to the terminating time, and risk is a nonlinear function, the portfolio optimization model turns out to be a mixed integer nonlinear programming when the terminating time is taken as a discrete variable, and a complicated nonlinear programming when the terminating time is taken as a continuous variable. We propose two methods for solving the portfolio optimization models, and test the algorithms with numerical computing experiments.

3 - Contingent capital: Short-selling incentives and discretionary triggers
Mark Reesor, Adam Metzler

Contingent Capital (CoCo) is designed to avoid bailouts of financial institutions (FI). CoCos are instruments that are debt (or preferred shares) when issued and that convert to common equity when the issuing FI is in financial distress. Conversion has the effect of recapitalizing the FI exactly when it would be most difficult for them to raise funds in capital markets through the issuance of new securities. There is no standard set of terms for CoCos and the properties of CoCos vary depending on the conditions that trigger conversion and the number of common shares that CoCo holders receive upon conversion. Our modelling framework allows for general capital structures and asset value dynamics to change upon conversion. The last feature is important as upon conversion the firm no longer pays interest on the CoCos, hence pushing the drift of the asset value process towards a more favourable financial condition. This framework still allows for the analysis of CoCo design and the model is easily calibrated to data. We discuss incentives for CoCo investors to short the issuing firm's stock in order reap profits by artificially forcing conversion. Additionally, it is common for regulators to have some discretion on when CoCos convert which induces some ambiguity on the trigger conditions. We discuss how CoCo design can make its value less sensitive to this ambiguity and relate this to the short-selling incentives mentioned above. This is joint work with Jingya Li of TD Bank.

4 - Term structure modeling of negative interest rates
Sing Fan Chan, Qi Wu

The low interest rate environment presents a challenge for the existing term structure models. In this paper, we propose a framework to construct new models from existing ones so that we can control how negative the conditional probability of interest rates could be. We apply this approach to the Nelson-Siegel model and, upon calibration, we found that bond yields from Euro area and Japan markets strongly prefer our proposed model framework, especially in periods when interest rate levels are around or below zero.

■ TA-13

Tuesday, 8:30-10:00 - 207

Personnel scheduling 1

Stream: Scheduling problems in logistics
Invited session
Chair: *Sanja Petrovic*

1 - Empirical studies on airplane boarding
Simone Neumann, Leonie Hutter, Florian Jaehn

Airplane boarding is a topic that receives increasing attention in scientific literature. Shorter boarding times can reduce the time an airplane spends at the gate (the airplane turn-around time) and hence cost savings can be realized. Although several papers exist that analyze the boarding process purely theoretically or with the help of simulation models, there is very little empirical research. In this talk, we present the results of an empirical study which was conducted at a large European airport. The aim of the study was to check whether and to what extend certain factors like the number of passengers, the capacity of the airplane or the number of carry-on baggage influence the boarding time. For this, boarding times and additional data for short- and medium-haul flights with single-aisle airplanes were collected and analyzed. By means of machine learning methods we develop a regression model for predicting the boarding time on the basis of the number of passengers and the capacity of the airplane.

2 - Optimization of employee shift schedules with inter-department transfers
Dalia Attia, Guy Desaulniers, Francois Soumis

The employee scheduling problem, in a multi-department context, aims to build employee schedules covering all demands, with the least cost. The demand of a department is covered either by its internal employees, or by transferred external employees. This problem can be modeled as an integer problem that is intractable for large real-life instances. In this talk, we propose a three-phase heuristic that solves a relatively small integer program in each phase. The first phase identifies where demand can remain uncovered if only internal shifts are used, and which department can offer employees for transfer to cover it up. The second phase solves, for each department, a mono-department employee scheduling problem, taking advantage of information gathered during the previous phase. The final phase fulfills any remaining demand using available employees from other departments. We will present computational results on large-sized instances which show that this heuristic can produce high-quality solutions in relatively fast computational times.

3 - Fairness staffing for a multi-skill call center
Göran Svensson, Per Enqvist

Modern inbound call centers often operate in multi-skilled environments. The use of multi-skilled agents contributes to balancing variations in the different customer skill demands. Therefore, the staffing needs and scheduling of agents should be based on the demand of the different skills, that can be time-varying and random, and take into account the conditions of both the customers and agents. Attrition rates are commonly high, and thus a real problem for call centers. Therefore, we propose that a fairness criterion should be included in the modeling, where the goal is to achieve fair long term work-loads between the agents. To promote a positive customer experience, we include one or more quality of service measures. The system is modeled with homogeneous Poisson arrivals of different types of customers. As the customers enter the system, they either wait for service or receive service, by agents with the appropriate skills. The agents are distributed among a set of agent pools, where each agent pool caters to a certain subset of customer skill demands. The goal is to find the optimal staffing levels for the agent pools. We develop a mixed integer linear program to solve the staffing problem, under a random routing paradigm, with constraints on agent fairness. The program is then extended to include bounds on selected quality of service measures. We also formulate a robust staffing requirement by including varying arrival-rate scenarios to handle arrival-rate uncertainty.

4 - Nurse rostering with well-being measures
Sanja Petrovic, Jane Parkin, Timothy Curtois, David Wrigley

This research is motivated by the findings of employee well-being at work mostly carried out in the field of occupational medicine. The aim of this paper is to bring the concepts of employee well-being to the timetabling community, and especially to consider the effect of shift working and different shift patterns in rostering. Based on the studied literature we suggest four well-being measures to be used in rostering including work-life balance measures, fatigue and risk indicators, and deviations from Health and Safety Executive (HSE) guidelines. A nurse rostering problem is chosen as an experimental environment because it is a highly constrained employee timetabling problem for which a large number of methods have been developed and problem instances are widely available. The well-being measures are employed together with traditional objective functions to create rosters. We investigate to what extent the proposed well-being measures can be attained without compromising the performance of roster. The experiments demonstrate that it is possible to maintain good performance measures of rosters and at the same time improve well-being of employees by assigning appropriate weights to well-being components in the objective function. This gives a rather powerful tool to the manager/scheduler to construct rosters by considering given regulations, employee preference but also well-being of employees.

■ TA-14

Tuesday, 8:30-10:00 - 305

MCDA applications and new research directions 1

Stream: Multicriteria decision analysis
Invited session
Chair: Valentina Ferretti

1 - A structured decision support framework for risk assessment of energy technologies
Marco Cinelli, Matteo Spada, Milosz Kadzinski, Roman Slowinski, Peter Burgherr, Stefan Hirschberg

The provision of operational guidelines for safe, reliable and resilient energy systems is one of the main objectives of the Future Resilient Systems (FRS) programme of the Singapore-ETH Centre (http://www.frs.ethz.ch/). The focus of this presentation will be on the structured decision support framework that is under development within the FRS programme to lead the evaluation of risks of accidents for different energy technologies, supporting the advancement of pre-event strategies within the proposed framework for infrastructure resilience assessment. Comprehensive accident information is based upon the most authoritative information source for accidents in the energy sector, i.e. the ENergy-related Severe Accident Database (ENSAD) of the Paul Scherrer Institut (PSI). One core component of the framework is the construction of criteria used to assess the risk, which includes location information (e.g. country, place), chain-related details (e.g. event classification, type of energy chain) and additional case-specific data. The individual stages of the construction of criteria will be presented, and their insertion in Multiple Criteria Decision Aiding methods will be discussed. Decision support models that can be developed to rank or classify accidents for energy technologies according to specific characteristics such as chain stages and infrastructure elements, depending on severity (e.g. fatalities, injuries) scales, will be discussed and conclude the talk.

2 - Synthesizing a set of rules by a noncompensatory sorting model: An application to environmental evaluation
Valérie Brison, Marc Pirlot, Antoine Rolland

Environmental evaluation often requires to aggregate several indicators of ecosystem services in a single criterion which reflects the overall environmental value. Such aggregation models are generally described by rules provided by experts. In case these rules are many, there is an advantage at summarizing them in a more compact formulation. The noncompensatory sorting model (Bouyssou-Marchant, 2007) is such a compact formulation, which is based on a majority rule and the absence of veto (in the spirit of outranking methods such as ELECTRE TRI, Roy-Bouyssou, 1993). We illustrate this idea on a real environmental assessment project and we examine, in general, the conditions on sets of rules which allow to synthesize them by this model.

3 - Predictive analytics and disused railways requalification: insights from a post factum analysis perspective
Milosz Kadzinski, Valentina Ferretti, Krzysztof Ciomek

The requalification of an abandoned railway line is a complex decision-making problem involving multiple and conflicting perspectives. In this study we take into account the preferences of representatives of a public entity and a private organization and we focus on the best performing projects for the requalification of an abandoned railway line in the North of Italy. Such recommendation is used as an input within a framework of post factum analysis that considers the impact of performance changes on the obtained results. In particular, we are investigating the minimal improvement of actions' performances on particular criteria that would warrant feasibility of some currently impossible outcome as well as the maximal deterioration by which some already attainable result would still hold. The considered target outcomes concern attaining a particular rank or being preferred to another action. By discussing the required or allowed changes in view of, for example, the expected duration of construction works, the costs, the number of potential users or the extension of new green areas, we demonstrate the usefulness of post factum analysis in terms of planning and formulating robust recommendations.

■ TA-15

Tuesday, 8:30-10:00 - 307A

Methods and algorithms in convex optimization 1

Stream: Continuous optimization (contributed)
Contributed session
Chair: Jie Tao

1 - Strong and stable strong Fenchel-Lagrange duality in evenly convex optimization problems

Maria Dolores Fajardo, Jose Vidal

Given a general primal problem and its Fenchel-Lagrange dual one, which is obtained via pertubational approach by using a generalized conjugation scheme called c-conjugation, the aim of this work is to establish conditions under which strong duality can be guaranteed. To this porpurse, even convexity will be a compulsory requirement for the involved functions of the primal problem. Two closedness-type sufficient conditions and a characterization are derived. We compare them and conclude the work extending these conditions to the study of stable strong duality.

2 - A new data qualification in convex multiobjective semi-infinite programming

Margarita Rodríguez Álvarez, Miguel Goberna, Virginia N. Vera de Serio

In this talk we characterize the weak efficient solutions and the efficient solutions of convex multi-objective programming problems with an arbitrary number of constraints by means of Karush-Kuhn-Tucker type optimality conditions through the introduction of a very general data qualification (DQ in brief), condition involving the objective functions and the constraint functions.

3 - On a convex resource allocation problem with nested lower and upper constraints

Thibaut Vidal, Daniel Gribel, Patrick Jaillet

We study a convex resource allocation problem in which lower and upper bounds are imposed on partial sums of allocations. This model is linked to a large variety of applications, including production planning, lot sizing, speed optimization, stratified sampling, support vector machines, portfolio management, and telecommunications. We introduce a gradient-free divide-and-conquer algorithm, which uses monotonicity arguments to generate valid bounds from the recursive calls, and eliminate linking constraints based on the information from sub-problems. These principles are quite unusual: the algorithm is not based on greedy steps and scaling, or even flow propagation, as it is often the case for this family of problems. It also does not need strict convexity or differentiability, and improves upon the best known complexity for this problem, producing a solution to the integer version of the problem (or an epsilon-approximate solution to the continuous version) in linearithmic time as a function of the problem size. Our experimental analyses confirm the practical performance of the method, which produces optimal solutions for problems with up to one million variables in a few seconds. Promising applications to the support vector ordinal regression problem, for machine learning, are also investigated.

4 - Global linear convergent algorithm to compute the minimum volume enclosing ellipsoid

Jie Tao

The minimum volume enclosing ellipsoid (MVEE) problem is an optimization problem in the basis of many practical problems. This paper describes some new properties of this model and proposes a first-order oracle algorithm, the Adjusted Coordinate Descent (ACD) algorithm, to address the MVEE problem. The ACD algorithm is globally linear convergent and has an overwhelming advantage over the other algorithms in cases where the dimension of the data is large. Moreover, as a byproduct of the convergence property of the ACD algorithm, we prove the global linear convergence of the Frank-Wolfe type algorithm (illustrated by the case of Wolfe-Atwood's algorithm), which supports the conjecture of Todd. Furthermore, we provide a new interpretation for the means of choosing the coordinate axis of the Frank-Wolfe type algorithm from the perspective of the smoothness of the coordinate axis, i.e., the algorithm chooses the coordinate axis with the worst smoothness at each iteration. This finding connects the first-order oracle algorithm and the linear optimization oracle algorithm on the MVEE problem. The numerical tests support our theoretical results.

■ TA-16

Tuesday, 8:30-10:00 - 308A

Intelligent DSS

Stream: Decision support systems
Invited session
Chair: K. Nadia Papamichail

1 - A next-item recommendation approach based on Borda majority count

Li-Ching Ma

Sequential pattern mining is an important data mining technique to find frequent time-related behavior from a sequential database. Mining sequential patterns can discover the sequential purchasing behavior for most customers from a big transaction database. This study aims to propose a new next-item recommendation approach incorporating the concept of bit-string operation, the PrefixSpan algorithm and the Borda majority count. The concept of the PrefixSpan algorithm is employed to divide the sequence database into several projected databases to increase computational efficiency. The projected Borda majority count matrices are generated based on different prefix item. By examining local frequent relationships in each projected matrices, the order of next recommendation items can be found. The proposed next-item recommendation approach can be widely applied in solving many real world business problems.

2 - New evidential reasoning modelling approach for data-driven system analysis and prediction

Shuaiyu Yao, Jian-Bo Yang, Dong-Ling Xu, Paul Dark

This paper aims to develop a novel data-driven Evidential Reasoning (ER) modelling approach for system analysis and inference, which is based on the acquisition and combination of multiple pieces of evidence with reliabilities, weights, and dependence indices. In this paper, we first investigate the unified multi-model decomposition structure to partition the input space into local regions. On the basis of these local regions, the distributed approximation process of the novel ER modelling approach is demonstrated, in order to uncover the underlying inference mechanism equipping the novel ER modelling approach with superior approximation capability. The Sepsis data sets and Fishers' Iris data set are used to validate the probabilistic inference and prediction capability of the novel ER modelling approach, in comparison with alternative approaches e.g., logit regression, neural network, and support vector machine. This provides a solid foundation for applying the novel ER modelling approach for complex system analysis and decision making under uncertainty.

3 - The impact of organizational factors on knowledge sharing performance

Oluwafemi Oyemomi

Facing global challenges in the knowledge economy, the competitiveness of business organisations has transformed dramatically in recent years. With the increase in the significance of knowledge sharing to organisational growth, a lot of resources have been invested to the management of knowledge via technological applications. In the same line of argument, a wide range of literature has argued for the contribution of employees in the sharing of knowledge. However, very few literature has discussed the impact of organisational factors on the integration of business processes and knowledge sharing. Given the amount of research on the importance of knowledge management to improve business processes and organisational knowledge, it becomes imperative to develop a clear understanding of the impact of organisational factors on knowledge sharing performance. Therefore, the primary aim of this research is to measure the knowledge sharing efficiency of an organisation considering organisational factors for business-knowledge implementation. Various manufacturing and service organisations will potentially benefit from applying the results of this study to their knowledge sharing practices when seeking greater integration of multi business processes with accrued knowledge. The theoretical contribution of this study includes an integrated framework and model for knowledge transformation processes, knowledge sharing processes and knowledge sharing decision making for performance

4 - Factors affecting knowledge-based decision support systems in multinational corporations
Mahmoud Abdelrahman, K. Nadia Papamichail

The main aim of this study is to examine the impact of using Knowledge Management Systems (KMSs) on Knowledge Sharing (KS) to support decision-making processes (DMP) in Multinational Corporations (MNCs). This aim was achieved through conducting and analysing a literature review, followed by exploratory research with thematic analysis of 42 semi-structured interviews with partipants from Europe & Middle-East who are working in MNCs to identify the factors affecting KS. A set of strong overarching themes were identified in a conceptual framework comprising four core dimensions. In the first dimension Knowledge Management Systems, three themes were identified: Technology Acceptance, Communication Tools, and KMSs Usage. In the second dimension Knowledge Sharing Practices, three themes were identified: Content, Willingness to Share, and External Factors (i.e: politics, corruption). In the third dimension Culture, the three themes were: National Culture, Organisational Culture, and Information Technology Culture. In the fourth dimension Decision-making Processes: Extent of Analysis and Speed of Decision-making were identified. The conceptual framework will make important contribution to the literature in Information Systems, Operational Research and Decision Support Systems which will help MNCs to identify new ways of leveraging and sharing knowledge to support the DMP. The findings give fruitful insights to managers inside MNCs to improve KS by using KMSs to support the DMP.

■ TA-17

Tuesday, 8:30-10:00 - 309A

DEA and performance measurement 2

Stream: DEA applications
Invited session
Chair: Yu Yu

1 - Performance assessment of Portuguese wastewater treatment plants using data envelopment analysis
Ana Camanho, Alda Henriques, Milton Fontes, Pedro Amorim, Jaime Gabriel Silva

This study develops a framework to assess the performance of wastewater treatment plants (WWTPs). The Data Envelopment Analysis benchmarking technique is used to identify potential improvements in utilities' operation. The procedure proposed can have a key role in the enhancement of operational methods and asset management systems supporting utilities activity. This research contributes to a better understanding of WWTP performance, helping utility managers to fast detect and monitor efficiency degradation. Potential performance improvements are sought in terms of resources' utilization (energy and labour), considering the amounts of pollutants removed and the volume of wastewater treated. It is given particular attention to resources usage, as operational costs are one of the most important indicators that professionals need to consider for the prioritization of assets replacement or refurbishing investments. The approach proposed also includes the analysis of the influence of contextual factors on the performance of the WWTPs (e.g., plant size, percentage of utilization of the installed capacity, sewage biodegradability, type of secondary treatment technology, plant age, the existence of tertiary treatment and nutrient removal). The framework developed in this research is illustrated with a real-world case study, using the WWTPs of a Portuguese water company. The managerial implications of the results are also discussed.

2 - A performance framework for European museums
Stella Sofianopoulou

The aim of this study is to investigate the performance measurement and evaluation of European museums. Without ways to measure museums' performance, museums will remain unaccountable in the current world, that demands accountable results (Jacobsen, 2016). The performance measurement of museums under investigation consists of financial and personnel performance, although other performance indices can be taken into account. The model consists of implementation of Data Envelopment Analysis (DEA) approach, that is used to measure relative efficiency in these institutions. Several studies, some of them quite recent, have employed various models to investigate the performance of museums. DEA in particular has been used to evaluate a group of institutions that employ different inputs to produce outputs (Del Barrio and Herrero (2009, 2013), Fernández-Blanco, 2013). In this work, we employ DEA, a methodological approach, to analyse the efficiency of a homogeneous group of museums that use a series of inputs (labour, expenditures) to achieve a set of outputs (visitors). This method can help museums to compare their institution with their peer, discover the gap in their resources or outputs and can be utilized as a tool that shows that a museum is not performing as it should. In our sample investigated, there are museums with sufficient inputs and which are efficient in the outputs, whereas the less efficient ones could be considered oversized in terms of resources utilized.

3 - Evaluation of ecological systems and the recycling of undesirable outputs: An efficiency study of regions in China
Wanghong Li, Wade Cook

A balance between environmental regulation and economic prosperity has become a major issue of concern to attain a sustainable society in China. This study proposes the application of Data Envelopment Analysis (DEA) for measuring the efficiencies of the ecological systems in various regions of that country. The proposed approach differs from most of the previous ecological systems models in that we view it in a two stage setting; the first stage models the ecological system itself, and from an economic perspective, while the second stage (decontamination system) models water recycling as a feedback process, and the treatment of other undesirable outputs coming from the first stage. There, we separate polluting gases and water into two parts; one part is treated, while the other is discharged. The model considers two major desirable outputs from the first stage, namely Population and Gross Region Product by expenditure (GRP), as well as undesirable variables in the form of consumed water, and certain pollutants, namely nitrogen oxide, sulfur dioxide and soot. At the same time, these undesirable outputs from the first stage are inputs to the second decontamination stage. As well, recycled water is fed back into stage 1. Thus, intermediate variables such as consumed water and waste gas emission simultaneously play dual roles of both outputs and inputs in the ecological system.

4 - Measuring the R&D efficiency in China: A two-stage data envelopment analysis with time lags effects
Yu Yu

Although R&D efficiency has been widely studied using standard DEA (Data Envelopment Analysis) models and its variations. These standard DEA models were developed under the basic assumption that inputs of a specific period are consumed to produce outputs in the same period. This underlying assumption may not be valid in some situations such as performance evaluation on R&D activity. In R&D activity, the outputs of a specific period can be thought to be produced by consumption of not only inputs in the same period but also the inputs in multiple previous periods. In other words, inputs of a specific period can be considered to contribute to the outputs of several subsequent periods as well as the same period. There are some time lag between input period and output period. Furthermore, a regional R&D process contains two sub-processes, one is technology development and the other is economic application. Under this circumstance, a two-stage DEA model with time lags effect was established to solve the drawbacks of traditional DEA model. The newly developed models are applied to measure the regional R&D efficiency of China. Results indicate that R&D efficiency in China are heterogeneous. Beijing and

Guangdong are found to be efficient. The inefficiency in the R&D activities by this study indicates the underlying potential that can be tapped for the development and growth of provinces.

■ TA-18

Tuesday, 8:30-10:00 - 2101

Location, logistics, transportation and traffic 1

Stream: Location, logistics, transportation, traffic (contributed)
Contributed session
Chair: Hossein Zolfagharinia

1 - A study on the operational problems at the outbound side of a distributor cross docking area
Ying-Chin Ho, Chih-Feng Chou

The environment of this study is a distributor cross docking area. In this environment, inbound trucks deliver different types of items to the cross docking workplace and place them in temporary storage blocks. Human pickers collect items from temporary storage blocks according to customer orders and place them on palettes. Palettes with completed orders are loaded on outbound trucks which ship them to customers. Cross docking can achieve several advantages, e.g. less storage and handling cost, faster delivery of goods to customers and less storage space requirement. However, it is possible none of these advantages will be achieved, if cross docking is executed incorrectly and/or inefficiently. In this study, we study three operational decision problems at the outbound side of a distributor cross docking workplace. These problems include the problem of determining the processing priority of truck orders, the problem of assigning picking-storage blocks to truck orders and the problem of determining the processing priority of palette orders. Different solutions are proposed for each problem and simulation experiments are conducted to compare their performance in four different performance measures - on-time delivery rate, total tardiness, total system time and total picking travel distance. We hope that the knowledge learned from this study can assist distribution centers with similar crossing docking environments in improving their crossing docking performance.

2 - A study on putting-style order-picking operations in a sistributor cross docking area with multiple picking-storage-cell blocks
Chih-Feng Chou, Ying-Chin Ho

The environment of this study is a distributor cross docking area which has a single row of temporary storage blocks for incoming items and many picking-storage-cell blocks for outgoing items. In this environment, inbound trucks deliver different types of items to the cross docking workplace and place them in temporary storage blocks. In each picking trip, only one type of items will be delivered to orders. A picking person will drive a powered pallet truck which carries a pallet stacked with identical items and deliver items to picking-storage cells that need them. In other words, putting-style order-picking operations are performed. In this study, we study four operational problems. These problems include the problem of assigning picking-storage cells to truck orders, the problem of determining which item has higher priority to be picked first, the problem of selecting picking-storage cells that items can be delivered to and the problem of determining routes for distributing items to picking-storage cells. Different solutions are proposed for each problem. Simulation experiments are conducted to compare their performance in three different performance measures - total system time, total traveling distance of pickers and the total picking time of pickers. It is hoped that the knowledge learned from this study can assist distribution centers with similar crossing docking environments in improving their crossing docking performance.

3 - A study on the operational decision problems in a synchronized sequential-zone picking system with a flow-rack order-consolidation system
Shan-Nung Chu, Ying-Chin Ho

The environment of this study is a flow-rack order-consolidation system in a synchronized sequential-zone picking system. A synchronized sequential zone picking system is made up of two or more sequential-zone picking lines. When an order arrives at the system, it will be split into two or more sub-orders if the items it needs are located in two or more sequential-zone picking lines. Once the sub-orders of an order have completed their picking operations, they must be consolidated first before being shipped to the customer. In our environment, a flow-rack system is used for the order-consolidation purpose. In the picking process, totes are used to carry picked items. With this system, totes belonging to the same order will be placed on the flow-rack lanes assigned to the order. In this study, we study three operational decision problems that can affect the performance of the flow-rack order consolidation system. These problems include the problem of determining the processing priority of orders, the problem of assigning lanes to orders and the problem of determining the processing priority of totes. We propose different solutions for each problem and conduct simulation experiments to compare their performance in two performance measures - total system time and total busy time of order consolidation operators. It is hoped that the knowledge learned from this study can assist distribution centers with similar environments in improving their order-picking performance.

4 - Time window discretization method for a dynamic truckload pickup and delivery problem
Hossein Zolfagharinia

This study addresses a dynamic pickup and delivery problem with full truckload for local operators. Some operational details such as dwell and delay times are considered in modeling the problem. The main purpose of this work is to design an algorithm based on a special case of this problem where no lateness is allowed. The proposed algorithm is built on the time window discretization method. We first discuss the convergence of this algorithm to the optimal solution and then test its computational efficiency under a variety of network settings. The results show that the developed approach is promising for small and medium trucking companies even when adequate advance information is available.

■ TA-19

Tuesday, 8:30-10:00 - 2102AB

Riemannian optimization

Stream: Riemannian optimization and related topics
Invited session
Chair: Orizon P Ferreira

1 - Image space analysis for generalized optimization problems on Hadamard manifolds with applications
Zhou Liwen

In this speak, a generalized optimization problem (GOP) with respect to the cone on the tan-gent space is introduced and studied on a Hadamard manifold. By introducing the image space analysis for (GOP), two necessary and sufficient conditions to characterize the existence of solutions for (GOP) are given on a Hadamard manifold. We give a separation theorem on a Hadamard manifold to characterize the existence of solutions for (GOP) by using the level set of the separation functions. Moreover, a generalized saddle point condition and duality are also established.

2 - Iteration-complexity of gradient, subgradient and proximal point methods on Riemannian manifolds
Glaydston Bento, Orizon P Ferreira, Jefferson Melo

In my talk I will consider optimization problems on Riemannian manifolds and will analyze iteration-complexity for gradient and subgradient methods on manifolds with non-negative curvature. By using tools from the Riemannian convex analysis and exploring directly the tangent space of the manifold, is obtained different iteration-complexity bounds for the aforementioned methods, thereby complementing and improving related results. Moreover, is also established the iteration-complexity bound for the proximal point method on Hadamard manifolds.

3 - Enlargement of monotone vector fields and an inexact proximal point method for variational inequalities in Hadamard manifolds
Orizon P Ferreira, Edvaldo E. A. Batista, Glaydston de Carvalho Bento

In this paper, an inexact proximal point method for variational inequalities in Hadamard manifolds is introduced and its convergence properties are studied. To present our method, we generalize the concept of enlargement of monotone operators, from a linear setting to the Riemannian context. As an application, an inexact proximal point method for constrained optimization problems is obtained

■ TA-20

Tuesday, 8:30-10:00 - 2103

Optimization of gas networks 1

Stream: Optimization of gas networks
Invited session
Chair: Martin Schmidt

1 - Dynamic compressor optimization in natural gas pipeline systems
Terrence W.K. Mak, Pascal Van Hentenryck, Anatoly Zlotnik, Russell Bent

The growing dependence of electric power systems on gas-fired generators to balance fluctuating and intermittent production by renewable energy sources has increased the variation and volume of flows withdrawn from natural gas transmission pipelines. Adapting pipeline operations to maintain efficiency & security under these dynamic conditions requires optimization methods accounting for substantial intraday transients and can rapidly compute solutions in reaction to generator re-dispatch. We present a computational efficient method for minimizing gas compression costs under dynamic conditions described by time-dependent mass flows. The optimization method uses a simplified representation of gas flow physics, provides a choice of discretization schemes in time & space, and exploits a two-stage approach to minimize costs and ensure smooth and physically meaningful solutions. The optimization scheme is validated by comparing the solutions with an integration of the dynamic equations using an adaptive time-stepping differential equation solver, and also a recently proposed optimal control scheme. The comparison shows that solutions to the discretized problem are feasible for the continuous problem and also practical from an operational standpoint. The results also indicate that our scheme produces at least an order of magnitude reduction in computation time relative to the state-of-the-art and scales to large gas transmission networks with more than 6k km of total pipeline.

2 - MIP-based instantaneous control of mixed-integer PDE-constrained gas transport problems
Martin Schmidt, Martin Gugat, Günter Leugering, Alexander Martin, Mathias Sirvent, David Wintergerst

We study the transient optimization of gas transport networks including both discrete controls due to switching of controllable elements and nonlinear fluid dynamics that are described by the Euler equations. This combination leads to mixed-integer optimization problems subject to nonlinear hyperbolic partial differential equations on a graph. We propose an instantaneous control approach in which suitable Euler discretizations yield systems of ordinary differential equations for which solutions can be derived analytically. This leads to finite dimensional mixed-integer linear optimization problems for each time step that can be solved to global optimality using general-purpose solvers. We show the capabilities of our approach in practice by presenting numerical results of realistic gas transport networks.

3 - A MILP-hierarchy for MINLPs from gas transport optimization
Lars Schewe, Robert Burlacu, Bjoern Geissler

We show how a hierarchy of MILP-relaxations can be used to solve optimization problems from stationary gas network optimization. To this end, we formulate the problem as a MINLP and then formulate our MILP-relaxation. The main feature of the proposed approach is an a-priori guarantee on the approximation error of the solution to the underlying MINLP. We discuss the underlying theory and show new computational results on gaslib-instances. We also discuss how these methods can be extended to the instationary case.

4 - Convex relaxations for gas expansion planning
Pascal Van Hentenryck, Russell Bent, Hassan Hijazi

Expansion of natural gas networks is a critical process involving substantial capital expenditures with com- plex decision-support requirements. Given the nonconvex nature of gas transmission constraints, global optimality and infeasibility guarantees can only be offered by global optimisation approaches. Unfortunately, state-of-the-art global optimisation solvers are unable to scale up to real-world size instances. In this study, we present a convex mixed-integer second-order cone relaxation for the gas expansion planning problem under steady-state conditions. The underlying model offers tight lower bounds with high computational efficiency. In addition, the optimal solution of the relaxation can often be used to derive high-quality solutions to the original problem, leading to provably tight optimality gaps and, in some cases, global optimal solutions. The convex relaxation is based on a few key ideas, including the introduction of flux direction variables, exact McCormick relaxations, on/off constraints, and integer cuts. Numerical experiments are conducted on the traditional Belgian gas network, as well as other real larger networks. The results demonstrate both the accuracy and computational speed of the relaxation and its ability to produce high-quality solutions.

■ TA-21

Tuesday, 8:30-10:00 - 2104A

Quayside operations

Stream: Port operations
Invited session
Chair: Ramon Alvarez-Valdes

1 - A mathematical formulation to solve the staff rostering problem minimizing the risk derived from heavy loads handling and repetitive movements
Massimo Paolucci, Claudia Caballini, Tommaso Napoli

The kind of activities performed in seaports can be highly risky for the safety and health of workers. The European regulation related to safety in workplaces, and its relative applications in the Member States, impose to seaports the respect of specific safety measures for the workforce subjected to the handling of heavy loads and repetitive movements. Seaport terminals must comply with this regulation, in order to safeguard the health of workers and not to incur in legal responsibilities in case of accidents or permanent damages to workers' health. The goal of the present work is to solve the staff rostering problem in a seaport container terminal taking into account the specific operative conditions and with the objectives of minimizing the total workforce risk and balancing such risk among workers. To this aim, a Mixed Integer mathematical programming model has been proposed, considering constraints such as the satisfaction of the workforce demand to execute the terminal operations, the worker-task compatibility and restrictions on the sequence of tasks assigned to the same worker. Note that the problem can be easily customized on the basis of different terminal operative rules. The model has been tested and validated on the data provided by a real container terminal located in Northern Italy for a six months horizon planning problem. Possible effective solution approaches for this problem will be discussed during the conference.

2 - An exact and heuristic approach to the berth allocation problem in terminals with irregular quays

Thomas Van den Bossche, Juan Correcher, Ramon Alvarez-Valdes, Greet Vanden Berghe

More than ninety percent of current world trade is undertaken by the shipping industry, exerting high pressure on terminals. The Berth Allocation Problem (BAP) constitutes a critical problem such terminals face when attempting to optimize their operations. This problem consists of assigning a time-slot and compatible berth for each incoming vessel. While significant research has previously been conducted regarding the BAP in container terminals, little attention has been paid to it in the context of complex terminal layouts. The present work considers the discrete BAP in a tank terminal consisting of irregular quays wherein adjacent, opposite, and indented berths impose various blocking concerning both the berthing and sailing of vessels. An exact approach based on a MIP model is introduced to tackle small instances and a heuristic approach based on the Multi-Depot Vehicle Routing Problem with Time Windows (MD-VRPTW) is employed when facing larger ones. Experiments are conducted on benchmark instances derived from a real-world case. The exact approach proves capable of providing optimal solutions for small to medium-sized instances, whereas the heuristic delivers high-quality results in reasonable computational time for larger instances. Future work will extend the model by including various other real-world problem characteristics, such as selecting the best tank regarding throughput so as to minimize the vessels' handling time.

3 - Berth allocation at a bulk terminal with storage capacity constraints

Guoqing Wang

We study the berth allocation problem at a bulk terminal where the unloading operations on import vessels are bounded by the dynamic storage yard capacities. Two models of the storage capacity, i.e., general storage capacity which bounds the total unloading volume in a given time period and individual storage area capacity which bounds the maximum volume of vessels to be accommodated in a specific storage area, are considered. For the discrete static berth allocation problem with general storage capacity constraints, we develop an efficient algorithm. For the problem with individual storage area capacities, we show that it is strongly NP-hard and develop a series of optimality properties.

4 - A new mixed integer linear model for the berth allocation and quay crane assignment problem

Ramon Alvarez-Valdes, Juan Correcher, Jose Tamarit

Efficient management of operations in seaport container terminals has become a critical issue, due to the increase in the maritime traffic and the strong competition between ports. In this paper we focus on the seaside operational problems: Berth Allocation and Quay Crane Assignment Problems, which are considered in an integrated way. For the continuous BACAP problem with time-invariant crane assignment we propose a new mixed integer linear model in which the vessels can be moored at any position in the quay, not requiring any quay discretization. The model is enhanced by adding several families of valid inequalities. The resulting model is able to solve instances with up to 50 vessels and outperforms other recently published proposals. In a second part, the model is extended to include the assignment of specific cranes to each vessel, BACASP. This assignment ensures that the handling of each vessel can be done without disruptions, thus producing solutions that can be applied in practice. We have also developed an iterative procedure for the BACASP. The BACAP model is solved and whenever its solution is not feasible for BACASP cutting planes are added until an optimal solution for BACASP is found. The computational study on several classes of test instances shows that problems with up to 50 vessels can be solved to optimality.

■ TA-22

Tuesday, 8:30-10:00 - 2104B

Stochastic programming algorithms and applications

Stream: Simulation, stochastic programming and modeling (contributed)

Contributed session

Chair: Julian Gonzalez

Chair: *Anirudh Subramanyam*

1 - A new algorithm for solving two-stage robust optimization problems with mixed-integer recourse

Anirudh Subramanyam, Wolfram Wiesemann, Chrysanthos E. Gounaris

Multi-stage decision-making problems with continuous recourse have been successfully addressed by robust optimization techniques over the last decade; however, problems with integer recourse still pose a major computational challenge. In this work, we address two-stage robust optimization problems with mixed-integer linear recourse. In particular, we present a new algorithmic framework for solving the corresponding K-adaptability approximations of these problems, in which the decision-maker commits to K sets of recourse policies here-and-now and implements the best policy once the uncertain parameters are observed. By viewing the K-adaptability problem as a semi-infinite disjunctive program, our solution approach is to use a sampling-based disjunctive branch-and-bound search procedure to converge to an optimal solution. Our framework is able to address mixed-integer decisions and random recourse in K-adaptability problems for the first time and is also able to incorporate a wide variety of decision rule structures for continuous recourse decisions that have been proposed in the literature. We conduct extensive numerical experiments on benchmark data from a number of popular applications including capital budgeting, shortest path and project management problems, which indicate that our proposed approach is practically tractable and improves upon the current state-of-the-art.

2 - An efficient algorithm for solving nonsymmetric multistage mixed 0-1 convex stochastic problems

Eugenio Mijangos

We present an algorithm to solve multistage mixed 0-1 stochastic problems with nonlinear convex objective function and convex constraints. These problems have continuous and binary variables in each stage. In previous works the number of contingencies was the same in all the nodes in the same stage. In this one we consider that the number of contingencies of the nodes is not the same in at least one stage, i.e. the uncertainty is represented by a nonsymmetric scenario tree. The algorithm is based on the Branch-and-Fix Coordination method (BFC). The non-anticipativity constraints are satisfied by means of the twin-node family strategy. In order to solve each nonlinear convex subproblem generated at each node of the trees of the BFC method we propose the solution of sequences of quadratic subproblems. As constraints are convex we can approximate them by means of outer linear approximations. The algorithm has been implemented in C++ with the help of Cplex 12.1 to solve quadratic approximations. Test problems have been randomly generated by a C++ code. Computational tests have been performed and its efficiency has been compared with that of KNITRO and BONMIN codes.

3 - Pension fund ALM with stochastic dominance constraints and hedging derivatives
Sebastiano Vitali, Milos Kopa, Vittorio Moriggia

The main goal of a pension fund manager is sustainability. We propose an Asset and Liability Management (ALM) model structured as a multi-stage stochastic programming problem adopting a discrete scenario tree and a multi-objective function. Among other constraints, we consider the second order stochastic dominance with respect to a market portfolio. To protect the pension fund from shocks we test the inclusion of hedge financial contracts in the form of put options and we introduce stressed scenarios using contamination techniques. Numerical results show that we can efficiently manage the pension fund satisfying liquidity, return, sponsor's extraordinary contribution and funding gap targets. We test sensitivity to put option strikes and to stochastic dominance constraints inclusion.

4 - A heuristic solution methodology for solving the Vehicle Routing problem with Stochastic Demands (VRPSD)
Julian Gonzalez, Luis Moreno

For the methodology, the VRPSD is modeled as a two stage stochastic integer programming problem with fixed recourse under an a priori optimization approach. The proposed heuristic method is divided in two phases; the first one samples a set of feasible routes using the route first - cluster second approach over a search space composed by subtours and TSP-like tours. The second phase solves a set partitioning problem in order to produce the set of routes that minimize the expected cost in the sample. The set of subtours for the routes sample in the first phase is generated from the sequential solution of assignment problems derived from the removal of the subtours elimination constraints for the traveling salesman problem over the graph. The other search space for the routes sample is composed by TSP-like tours made by cutting the different sets of subtours removing their longest arcs, creating chains that are then joined by its ends resulting in Hamiltonian tours over the whole graph while minimizing the cost of the joining process. The resultant sets of subtours and TSP-like tours are then sampled by a sweep method that treats them as cyclic orders, generating feasible routes for a set partitioning problem which is solved producing the optimal set of routes in the sample. The algorithm is tested against the best known methods in the literature obtaining good performance in terms of computational time and quality, comparing 40 known instances with Poisson demand.

■ TA-23

Tuesday, 8:30-10:00 - 2105

MADM principles 1

Stream: Multiple criteria decision analysis
Invited session
Chair: Jyh-Jiuan Lin

1 - Optimal assets allocation in high frequency data
Jyh-Jiuan Lin, Chih-Lin Wu, Chih-Chang Chiu, Ching-Hui Chang

This research devotes to providing the investors the proper investment strategies through the optimal asset allocation. There are several aspects need to be considered before one could approach the optimal strategies. First of all, the inputs of the objective function are the key ingredients to reach the minimum risk. Secondly, the marginal densities fitness of the assets and the correlation between the assets could fine tune the input estimation if the statistical methods are used properly. At last, the data frequency is also another ingredient of information. Different data frequency provides different microstructure information, therefore, lead to a different strategy. To achieve the goal, this research adopts the best fitted asset return marginal distribution out of six marginal densities, generalized Pareto distribution. Two copula models (normal copula and t copula) are incorporated to catch the correlation between the assets. Different portfolio sizes and rolling agenda settings are investigated. Using intra-day 5 minutes high frequency data, it is found empirically that the optimal portfolio return outperforms at portfolio size 25, adopting generalized Pareto distribution and normal copula model, rolling out and reinvesting weekly.

2 - An alternative of central limit theorem?
Ching-Hui Chang, Jyh-Jiuan Lin, Nabendu Pal

It is a common practice to approximate the sampling distribution of sample mean by normal distribution when n, the number of trials, is moderately large. But, when n is not large enough, say 25 or 30, then the usual normal approximation may not be a good one. In this talk we will show that the skew-normal distribution can provide a far better approximation due to its flexibility, and it can be used to approximate distributions other than the given examples.

3 - Designing an EQL based CUSUM chart
Tai-Yue Wang, Sheng-An Yang

The key characteristic of the Cumulative Sum (CUSUM) control chart is that the shift size of the mean shift is assumed to be known. When one specific size of the mean shift is assumed, the CUSUM chart can be optimally designed in terms of average run length (ARL). In practice, on the contrary, the shift size is usually unknown, and the CUSUM chart could perform poorly when the actual mean shift size is significantly different form the assumed size. In most research, one usually assumes or assigns a particular probability distribution to the size of the mean shift to represent the lack of knowledge of the shift size. However, this method is risky because real probability distribution of shift size may be different from the user-assigned (or assumed) distribution. In this study, we propose a methodology based on applying support vector machine (SVM) regression to the distribution fitting of the shift size. We first find the parameter of the chart by minimizing the Taguchi based function, called extra quadratic loss (EQL) function. EQL is used to evaluate the expected loss due to poor quality. In addition, this design decreases the risk that user directly assign distribution of the shift size and corresponds with the need of the enterprise because the EQL-CUSUM chart provides expected cost to the decision maker. Finally, the simulation study and the real data from the previous researcher are used to demonstrate the effectiveness of the proposed EQL-CUSUM chart.

4 - Application of functional data analysis in travel demand forecasting
Huey-Kuo Chen

In this research, we employed a dynamical functional prediction and classification (Chiou, 2012) with application to travel time prediction. The essential ingredient of the method is functional data analysis (FDA). The algorithm for the functional mixture prediction can be summarized as follows. Step 1. Identification of cluster subspaces. Step 2. Model fitting based on the historical or training data. Step 3. Prediction of the future travel time trajectory for a new and partially observed data conditional on clusters. Step 4. Prediction of travel time trajectory by the functional mixture prediction model. The research is conducted using Taiwan ETC data and the result obtained will further be compared with that from the empirical mode decomposition (EMD) method which is an essential module of Hilbert-Huang Transformation (HHT) (Huang, 1998; Wu and Huang, 2008; Chen and Wu, 2012). Both the proposed FDA method and the EMD method, though not exactly the same, employ the concept of decomposing original data into components and later aggregate the component predictions back into their original form. Since this type of travel time prediction methods is innovative and indeed more precise than many other previous prediction methods, extensive studies are definitely needed in order to fully exploit its merits in the immediate future.

■ TA-24

Tuesday, 8:30-10:00 - 301A

New findings through healthcare analytics

Stream: CORS SIG on healthcare
Invited session
Chair: *Marco Bijvank*

1 - Issuing policies for hospital blood inventory
Alireza Sabouri

We propose a model for allocating red blood cells for transfusion to patients, which is motivated by recent evidence suggesting that transfusing older blood is associated with increased mortality rate. We study the properties of blood issuance policies that balance the trade-off between "quality" measured in average age of blood transfused and "efficiency" measured in the amount of shortage. Based on our analysis, we design efficient issuance policies and evaluate their performance.

2 - Empirical investigation of current practices at emergency departments
Marco Bijvank

In 2012-2013, more than 40% of Canadian hospitals did not meet the targeted three-hour maximum wait time for at least 90% of the patients to be initially assessed by an emergency physician. Long wait times can be directly related to emergency department (ED) crowding. The problem underlying this phenomenon reflects a fundamental mismatch between the demand for emergency care and ED capacities. There is a unique opportunity to study ED processes in Calgary, since all EDs use an advanced and coherent computer system that tracks all activities initiated through it. Additionally, Calgary has one of the largest consolidated EDs in the world, with around 300,000 patient visits annually. Thus, there is a large amount of robust data available to quantify current operations. In this presentation, we identify what is causing these long waiting times, whether the bottlenecks change throughout the day, and what the impact is of their current practices. In particular, we focus on the fact that there are three types of areas at the ED: fast track area (patients with low severity), intake area (patients require no stretcher) and main area (remainder of patients). As a result, the average wait time in Calgary is almost the same for patients with severity scores of 3, 4 or 5 (1 being the most severe). Is this what is desired or should patients be prioritized differently?

3 - The affine accumulating priority queue
Maryam Mojalal, David Stanford, Richard Caron, Peter Taylor, Ilze Ziedins

Abstract: Until now, all models of the Accumulating Priority Queue presented in the literature have been based upon an assumption that all customer classes have no initial credits; that is, all arriving customers start to accumulate credits from a starting value of 0. The affine APQ model introduces a new element in terms of an initial class-dependent credit level, from which the accumulated priority grows linearly over time as with the initial level. In this presentation, we consider a two class APQ, and show initially how the initial priority score impacts the duration of the accreditation interval. We then assess the impact of the initial priority score on the waiting time distributions for the low and high priority classes. If time permits, numerical examples will be used to illustrate these concepts.

■ TA-25

Tuesday, 8:30-10:00 - 301B

OR for development and developing countries 1

Stream: OR for development and developing countries
Panel session
Chair: *Subhash Datta*
Chair: *Elise del Rosario*
Chair: *Olabode Adewoye*
Chair: *Maria Alejandra Castellini*

1 - The advantages of multi-methodology in the collaborative processes of knowledge building in Small and Medium Enterprises (SMEs)
Maria Alejandra Castellini, Jose Luis Zanazzi, Horacio Rojo, Mischel Carmen N. Belderrain

Management systems often have a high percentage of failures and non-compliances, which according to different authors; occur because some tasks do not make sense for persons who must operate these systems. To overcome the problem it is advisable to develop collaborative processes of knowledge building, in order to stimulate the elaboration of meaning within a group of people. For that purpose, a combination of Operational Research (OR), Statistics and Quality Management (QM) methodologies can be useful. Drawing on experiences from 120 OR and 30 QM projects conducted with SMEs in Argentina, the present work reports the ongoing research that explores the potential of using these multimethodologies (MM), within an SME context. As particular example, the problem of a supplier that outsources Information Technology projects, for which a team must be selected, is analyzed. In this case, Soft System Methodology (SSM) was applied to structure the problem; Repertory Grid for individual interviews and elicitation of the selection criteria; DRV, a multicriteria group decision making method, to assess the candidates and Linear Programming (LP) to assign people to each position. This MM has helped in establishing a systemic approach, which is adequate for the selection model to operate flawlessly. In addition, this MM has helped to understand the problem as well as generate knowledge and consensus on the selection process.

2 - A chaid analysis methodology for exploring sustainable practices for green supply chain management
Sadia Samar Ali

Urbanization and burgeoning technological advancement in different sector in India have brought the concept of green supply chain management, to highlight the importance of responsible consumption and production to maintain environmental quality, reduce wastage and bring about economic growth. Using survey method, data is collected from 54 manufacturing organizations from Pune Nashik area, and a comprehensive framework of sustainability measurement is developed through successive applications of CHAID analysis. The outcome gives us review of manufacturing sector and effect of implementation of green practices at different stages of supply chain. The research has managed to differentiate between the better performers of Indian manufacturing sectors which have contributed towards environmental sustainability through the inclusion of corporate policies focused on identifying and lowering cost which not only refers to money, but also includes the external costs of climate change, air pollution, dumping of waste, soil degradation, noise, vibration and accidents. Also the impact of inclusion of green practices at different stages of supply chain has been reviewed where green logistics takes the lead in improving the business performance along with better environmental sustainability.

3 - Impact of Strategies on reducing air pollution in Delhi—Bringing OR and Education to serve
Sadia Samar Ali, Archit Gupta

Air pollution remains one of the biggest concern for humans and their health. After the enactment of Air Act 1981, air pollution control programs have focused on most critical measures in terms of emissions, and many communities have benefited from these emission control programs. Nonetheless, most cities in the country still face continuing particulate non-attainment problems from aerosols of unknown origin (or those not considered for pollution control) despite the high level of control applied to many sources. As we know, air pollution and mortality in Delhi is increased by all-natural-cause morbidity and burning of fossil fuels, such as coal, oil, natural gas, and gasoline to produce electricity and power used by vehicles. Of late, the air pollution status in Delhi has undergone many changes in terms of the levels of pollutants and the control measures taken to reduce them. This study is based on primary research based on responses collected from academia (scientist, professors, students); business (industry and shop owners, and professional associated with them); government (economic zones areas, power plants, officials etc) officials . With the help of SAP-LAP(Situation-Actor-Process-Learning-Action-Performance) interactions and IRP(Interpretive Ranking Process) , researcher identified best strategies for actors, playing effective role in implementing various tactics for reducing air pollution in Delhi. The results are encouraging however, in future the role played by actors needs to be critically scrutinized in terms of the Goals, principles, research boundaries and methods.

■ TA-26

Tuesday, 8:30-10:00 - 302A

Convex optimization and equilibrium problems in electricity market

Stream: Equilibrium problems in energy
Invited session
Chair: *Mohammad Reza Hesamzadeh*
Chair: *Othmane Mazhar*

1 - An algorithmic approach to electricity spot market prediction with regime shift regression
Othmane Mazhar, Cristian Rojas, Mohammad Reza Hesamzadeh, Carlo Fischione

Price forecasting is of prime importance for the electricity market, as better forecasts permit to uncover hidden patterns, correlations and other insights for more confident decision making, and better decisions results in efficient operation and investment decisions, and reduced risk. The aim of this study is to use certain properties of the time series of electricity spot prices and external knowledge for better prediction. Specifically we use a regression model that takes into account the possible existence of multiple regimes that the prices might shift into. Traditionally price forecasting is done by either Hidden Markov model techniques of high accuracy that are prone to over fitting and shed few lights on the causes of the transitions, or regression models that are less accurate but permit more interpretability and are developed in an ad hoc fashion via trial and error. To accommodate the needs of accuracy, interpretability and generalization we have developed an algorithm for regression that uses an estimator flexible enough to fit multiple regimes and we penalize it by a combination of two sparsity inducing norms. One of the terms promotes sparse solution for more interpretability and the other helps to incorporate certain prior knowledge that one might want in the end result, instead of going trough a trial and error phase. Also, the formulation is robust to the existence of outliers. Finally a test and validation phase is introduced to prevent from over-fitting.

2 - Nash equilibrium in hydro-dominated systems under uncertainty: Modified Benders approach
Ekaterina Moiseeva, Mohammad Reza Hesamzadeh

We formulate the model for strategic interaction in hydro-dominated power systems under uncertainty as an equilibrium problem with equilibrium constraints (EPEC), reformulated as a stochastic mixed-integer linear program (MILP) with disjunctive constraints. We model strategic hydropower producers, who can affect the market price by submitting strategic bids in quantity, price, and ramp rate. The bids are submitted to the system operator, who minimizes the dispatch cost. We take into account the hydro-specific constraints and uncertainty in the system. Solving the problem results in finding Nash equilibria. We discuss different types of Nash equilibria under uncertainty: Bayesian Nash equilibria and robust Nash equilibria. We also propose a decomposition method for solving large EPEC instances – Modified Benders Decomposition Approach (MBDA). This method eliminates the problem of tuning the disjunctive parameter and reduces the memory requirements, resulting in improved computation time.

3 - The bi-level transmission expansion problem with a regulatory constraint
Dina Khastieva, Mohammad Reza Hesamzadeh

Well-planned electric transmission infrastructure is a foundation of a reliable and efficient power system operation. However, under current electricity market designs there are lack of incentive mechanisms which can guarantee optimal expansion planning. This paper proposes an incentive mechanism for transmission expansion planning described through a bi-level program and a solution methodology to address the problem. The upper level is a profit-maximization of an independent transmission company (Transco) while the lower level is a welfare maximization problem. The revenue of the Transco is bound by regulatory constraint set by the regulator. The proposed model is a bi-level mixed-integer disjunctive problem. Thus, in addition to the mathematical formulation of the problem this paper proposes a methodology to find an optimal solution in a reasonable computational time. The methodology includes various reformulation techniques such as Big-M and one-level equivalent reformulation. In addition, a modified Benders decomposition is proposed to further improve solution of the model without increasing computational time. The performance of the incentive mechanism is presented through a small illustrative example and further tested on large scale test systems to evaluate performance of decomposition techniques. The proposed mechanism produces welfare-maximum outcomes while proposed solution methodology guaranties its convergence to the optimum results.

4 - Modeling the oligopolistic competition of generators in two-settlement electricity markets: Two-stage stochastic EPEC approach
Mahir Sarfati, Mohammad Reza Hesamzadeh

This study proposes a two-stage Nash-Cournot game to study the oligopolistic competition of generators in sequential day-ahead and the real-time markets. We consider strategic generators in both markets. The two-stage Nash-Cournot game is formulated as a two-stage stochastic equilibrium problem with equilibrium constraints (EPEC). The two-stage stochastic EPEC is recast into a two-stage stochastic Mixed-Integer Bilinear Program (MIBLP). Using linearization techniques the number of bilinear terms in developed MIBLP is reduced. We use the Nonconvex Generalized Benders Decomposition (NGBD) and the Primal Relaxed-Dual (PRD) algorithms to decompose the two-stage stochastic MIBLP problem into several linear programs (LPs) and mixed-integer programs (MILPs). These LPs and MILPs are solved iteratively until the epsilon-global solution of the two-stage stochastic MIBLP is found. Using different high performance computing techniques embedded in GAMS environment the computation time is reduced. The developed two-stage stochastic MIBLP model and the NGBD-PRD solution algorithm are demonstrated on the 2-node, 6-node and IEEE 24-node example systems. The numerical results confirm the utility of the developed models for analyzing the oligopolistic competition of generators in considered two-stage market.

■ TA-27

Tuesday, 8:30-10:00 - 302B

Behavioural issues in decision making 2

Stream: Behavioural OR
Invited session
Chair: *Rudolf Vetschera*

1 - Role of feedback on bidding behavior in first price reverse auctions
Aysegul Engin

In normative decision making, having more information is assumed to lead to better decisions. However, interactions between boundedly rational subjects could lead to reverse effects. We test the effect of different amounts of information on the individuals' decisions in an experimental study with 208 subjects. The experiment consists of multiple rounds in a reverse first price auction framework with buyer determined ending rule. The 2 x 2 design of the experiment covers two different market and information conditions. In one market, one human subject bids against 7 computerized opponents. In the other market 8 human subjects bid against each other. After bidding, subjects receive feedback. The minimum feedback covers only, whether the subject won or lost the previous round and if the game ends. The maximum feedback includes other bids in the market, winning bid and subject's payoff for all previous rounds. Subjects are incentivized monetarily according to their performance in the experiment. Results show that the previous argument from normative decision making does not hold absolutely with boundedly rational decision makers. Bidding behavior depends on psychological traits of the individual as well as the value of the information. More information on opponent behavior sometimes triggers a bidding behavior that decreases subject's own revenue.

2 - Identifying the heuristics and biases in the prenegotiation preference elicitation
Ewa Roszkowska, Gregory Kersten, Tomasz Wachowicz

In this study we investigate if and what kind of cognitive heuristics and biases are used by the negotiators in the prenegotiation phase when analyzing the negotiation problem, eliciting their preferences and building the negotiation offer scoring systems. We consider the problem of the software supported bilateral negotiation, in which the agent negotiates on behalf of their principal, and the latter has defined their goals, priorities and preferences. In the prenegotiation, the agent has to build the quantitative negotiation offer scoring system that should reflect the principal preferences best using the direct rating technique. Such a scoring system is used later during the actual negotiation phase to evaluate the offers, measuring the concessions made by parties, visualizing the negotiation progress on the negotiation history graphs etc. Thus, it seems crucial for negotiators to determine such scoring systems thoroughly to reflect their preference in most accurate way. We focus on evaluating and analyzing the impact of scaling biases on the accuracy of the negotiation offer scoring systems and on their concordance with the preferential information provided to negotiating agents by their principals. In our study we analyze the dataset of bilateral electronic negotiations experiment conducted in Inspire negotiation support system.

Acknowledgements. This research was supported by the grant from Polish National Science Centre (2016/21/B/HS4/01583)

3 - Challenges and issues in building a shared model for multi-criteria group decision making: A case study from sustainable transportation
Francis Marleau Donais, Irene Abi-Zeid, Roxane Lavoie

Shared procedures to build a consensus within a group decision process are sometimes used in multi-criteria decision-making. Facilitators often face several challenges and the solutions to overcome them are scarce and not well documented. This project presents a case study within a decision framework that combines problem structuring with the multi-criteria decision aid method MACBETH in order to build a shared preference model in a sustainable transportation context. The transportation sector is a major source of greenhouse gas and has several environmental impacts like traffic congestion and urban sprawl. Designing streets that favour active transportation and transit is an effective way to decrease the transportation environmental impact. To succeed, the framework was applied with a group of professionals from Quebec City, Canada to assess and rank streets as a function of their potential to become Complete Streets. The professionals were Quebec City's municipal employees representing various municipal departments, including specialists in environment, engineering, transportation and urban planning. The analysis of the process showed that difficulties in expressing preferences, access to data during workshops, group size, group discussion management, and project length were encountered. Nonetheless, the proposed framework and the use of subgroups to build criteria scales were a way to overcome these challenges and allowed us to successfully complete the project.

4 - Factors influencing the ratio bias
Rudolf Vetschera, David Bourdin

The ratio bias refers to the phenomenon that decision makers tend to overestimate probabilities which are expressed as ratios of high numbers in comparison to probabilities expressed as ratios of low numbers. In the present paper, we extend previous research on the ratio bias by considering possible deviations both in favor of low- and high-number alternatives, as well as by allowing for indifference. Results indicate that a systematic deviation in favor of high-number alternatives does exist, and is influenced both by personal characteristics such as gender (the bias occurs more often among female subjects), and problem characteristics such as the level of probabilities involved (the ratio bias occurs more frequently for low probabilities). Furthermore, the ratio bias must be clearly distinguished from a general tendency to indicate indifference, that might work in favor of high-number as well as low-number alternatives. This tendency towards indifference is not as strongly related to the above mentioned external factors as the ratio bias.

■ TA-28

Tuesday, 8:30-10:00 - 303A

Admission and physician planning

Stream: OR in healthcare
Invited session
Chair: Jens Brunner

1 - Managing the admission and discharge processes in the intensive care unit
Jie Bai, Andreas Fügener, Jochen Gönsch, Jens Brunner

Intensive Care Units (ICU) are known as a crucial and expensive resource largely affected by uncertainty and variability. The resulting capacity limitation causes many negative effects for the ICU, and even making ICU a bottleneck in hospital patient flows. To tackle this problem, both admission control of newly arrival patients and demand driven early discharge of currently residing patients could be options. However, the rejection of new patients could increase mortality rates, and demand driven early discharges might result in deterioration of patient's health leading to increased readmission rates. Therefore, making optimal decisions to minimize the negative consequences of admission and discharge policies is important. We model the decision making problem as a discrete time Markov decision process (MDP) and compute the exact solution by backward dynamic programming (BDP). We discuss resulting optimal policies for both managerial and medical scenarios derived from empirical data.

2 - Flexible break assignment in physician scheduling
Melanie Erhard, Jens Brunner

In hospitals, personnel generate the biggest and most important cost. This research handles the physician planning problem in hospitals on an integrated level by focusing on the investigation of break assignments in the shift scheduling process as major objective. In particular, we consider four different approaches for modeling the flexible placement of breaks within shifts. Current scheduling literature mainly neglects the consideration of breaks whereas practice uses manual scheduling approaches that are time and cost intensive. Focusing on a strategic planning problem, we minimize the number of assigned physicians subject to demand coverage and labor regulations. We formulate the problem as mixed-integer programs and test various parameter settings. The problem is solved with standard software (like CPLEX). For our experimental study, real world data from a large hospital in Germany is used. All developed models assure an appropriate break assignment but runtime differs significantly per modeling approach. Computational results show that no consideration of breaks leads to a significant underestimation of the required workforce size and with this to an increase in staff utilization as well as resulting working hours in terms of overtime, especially under real life assumptions.

Moreover, legal regulated rest periods for physicians cannot always be ensured. Therefore, we recommend the consideration of break assignments.

3 - Handling overtime in physician scheduling
Jens Brunner, Andreas Fügener

We introduce stochastic demand for staffing using a scenario-based approach. To incorporate this kind of uncertainty, we extend shift scheduling by allowing variable shift extensions. We propose a mixed-integer linear program and present a column generation heuristic. Computational experiments demonstrate that unplanned overtime is reduced by more than 80 percent.

■ TA-29

Tuesday, 8:30-10:00 - 303B

Military, defense and security applications 4

Stream: Military, defense and security applications
Invited session
Chair: David Lowe

1 - Quantifying the residual risks associated to force protection postures
Mark Rempel, Raman Pall

The Canadian Armed Forces (CAF) employs Force Protection Measures (FPMs) to minimize the residual risk of personnel, facilities, equipment, and information to identified threats. Regardless of the asset type, the FPMs' effectiveness, both individually and in combination, to reduce risk is directly impacted by their design and implementation. However, quantifying the effectiveness of FPMs is difficult since, in general, it is hard to quantify the value of deterrence by denial. In this presentation, we propose a methodology to evaluate the effectiveness of FPMs to reduce an asset's risk. First, we describe how an individual FPM's effectiveness is measured by considering its design and implementation characteristics. Next, we show how the effectiveness of a combination of FPMs can be computed based on their degree of dependence. Lastly, we demonstrate how information about the effectiveness of FPMs and assets' residual risks can be combined to: (1) identify FPMs that may be causing the CAF to be exposed to undue risk; and (2) prioritize FPMs whose changes to design and implementation will likely lead to significant risk reductions to identified threats.

2 - A methodology to measure and monitor level of operational effectiveness of a CSOC
Ankit Shah, Rajesh Ganesan

Cybersecurity analysts are adequately staffed at a cybersecurity operations center (CSOC), under normal operating conditions, to analyze the amount of alert workload generated by intrusion detection systems (IDSs). There are number of factors that can adversely impact the normal operating conditions such as higher alert generation rates from IDSs, new vulnerability detection that decreases the throughput of the alert analysis process, and analyst absenteeism. As a result, the alerts wait longer before being analyzed, which impacts the Level of Operational Effectiveness (LOE) of the CSOC. LOE can be quantified and monitored by knowing the exact deviation of the CSOC conditions from normal and the time it takes to return to normal. LOE is quantified by defining a new metric called total time for alert investigation (TTA), which is the difference between the time at which an alert completed its investigation and the time of its generation in the system by the IDS. A dynamic TTA monitoring framework is developed and case studies are presented using real world data and adverse situations faced by the CSOCs. Using the insights about the current LOE of the system, a CSOC manager can quantify and color-code the LOE which allows for a deeper understanding of acceptable downtime for the IDS, acceptable levels for absenteeism, and the recovery time and effort needed to return to its ideal LOE. This study was supported and conducted with a joint collaboration with the Army Research Lab.

3 - Solving the moving target search problem using indistinguishable searchers
Francois-Alex Bourque

Searching for a single target in discrete space and time is a well-known problem in military OR that also finds applications in other areas such as search and rescue. Solving this problem is hard, as search routes depend on the knowledge of where the target may be at a given time, which itself changes as the search proceeds. It is even more so for multiple searchers, as the size of the state space now depends on the number of searchers. This contribution deals with this problem variant for a single moving target by assuming that searchers are not only identical, but also indistinguishable. In the standard branch-and-bound approach to this problem, this assumption permits to calculate bounds by solving min-cost flow problems, which are independent of the number of searchers and where there is no need to relax the integrality of the search effort. Both of these outcomes are novel in comparison to previous efforts with multiple searchers. The author illustrates the proposed approach in the context of a counter-piracy scenario where warships aim to deter and interdict pirates and where the pirate motion model derives from an environmental forecast of the likelihood of piracy and the Markov assumption.

4 - Multistage scheduling approach for defense planning based on a comprehensive capability view
Michael Preuß

Based on current multinational commitments, strategic objectives and guidelines of the German Federal Ministry of Defence as well as existing capabilities, the avoidance of gaps within the capability spectrum of the German Federal Armed Forces is one of the main tasks. Projects need to be prioritized and scheduled accordingly. To ensure a continuous, efficient and target-oriented capability management, we developed an integrated approach to meet challenges of this dynamic and complex environment. Especially the scheduling of projects which have to start within a predefined time frame is a challenging task in combination with predecessor relationships. To meet the challenges of the underlying NP-hard resource-constrained scheduling problem we developed an multistage scheduling approach based on an adapted genetic algorithm and design of experiments. After a first field trial we observed two more challenges. First of all the formalization of planning objectives can be determined with the help of an analytic hierarchy process. Secondly, there are also advantages by involving decision makers into the optimization process; therefore we expand our approach by a comprehensive management cockpit. In order to provide an appropriate decision support, we visualize the definition and solution space in an intuitive way.

■ TA-30

Tuesday, 8:30-10:00 - 304A

Planning under uncertainty

Stream: OR in forestry
Invited session
Chair: David Martell

1 - Optimization of harvest planning in forest stands infested by spruce budworm using stochastic programming
Iris Zhu Chen, Mustapha Ouhimmou, Mikael Rönnqvist

Harvesting is considered as one of the key critical processes as it provides the primary raw material for different mills in the forest industry. However, due to several natural disturbances such as insect outbreaks, the impact and the effects on the tactical planning of forest supply chain can be irreversible. We consider Spruce Budworm creating more susceptibility and vulnerability in trees over the time, and increasing mortality by defoliation. We formulate a deterministic Mixed Integer Linear Programming model which is extended into a Two-Stage

Stochastic Programming (SP) model to deal with uncertainty related to the severity and propagation of the infestation. This SP model aims to maximize the market value of the harvested logs considering the occurrence of infestation over all the possible scenarios; as well as tracking the levels of volume inventory of the forest stands regarding the Spruce Budworm life cycle. The model was implemented in the modeling language AMPL and solved using CPLEX solver. Preliminary results show the value of using SP in harvest planning under uncertainty and the cost of it. This model provides better decision making in forest management, reducing costs, increasing the impact in the entire value chain and loss of trees as Spruce Budworm can lead to future outbreaks. We analyze a real case study in the North Shore of Quebec (Côte-Nord) and compare deterministic and stochastic optimization methods.

2 - Location of suppliers and vehicle routing under uncertainty

Sattar Ezzati, Mikael Rönnqvist, Jean-Francois Audy

Transportation from supply points to industries is often costly and addresses significant coordination challenges to achieve long-term procurement goals. By properly choosing the supplier locations, transportation cost savings may be obtained, however it might be improved by incorporating possibilities for efficient vehicle routing and collaborating opportunities. Moreover, when potential available suppliers are estimated prior to choosing their locations, it needs the competitive companies sourcing in the neighborhood incorporated into the planning to better utilize transport capacity. Considering these decision elements in an integrated way may improve supplier coordination and visibility of industry demand where there is an uncertainty in the decision environments. In this research project, the idea is to identify and establish a mechanism that would integrate tactical decisions on the supplier locations, vehicle routing and inventory management. This project is done in collaboration with a Canadian pulp and paper company. In particular, we will explore how industries and suppliers can work together to better respond to mill's demand where uncertainty arises on the location and volume available of the supplier and unexpected shifts in demand pattern or disruptions in supply (i.e., both quality and quantity in the product) to ensure a relationship beneficial for all parties.

3 - Fiber procurement planning under sourcing uncertainties

Ali Rahimi, Mikael Rönnqvist, Luc LeBel, Jean-Francois Audy

Fiber procurement in the forest industry is challenging due to various uncertainties affecting supply operations. These uncertainties may cause, for instance, delayed deliveries or changed order levels on supply. Such lack of supply may lead to changed production or expensive purchases to compensate the shortage. When external suppliers are involved, selecting proper sourcing strategy under such circumstances can counteract the deviations in the volume of deliveries as a sourcing uncertainty. Also, companies need to manage level of safety stock in response to probable shortage and to prevent excess inventory cost. We propose a stochastic programming model, including both purchasing from external suppliers and internal operations (i.e., harvesting and transportation), with uncertain deliveries from suppliers. The objective of this model is to minimize the total procurement cost. The uncertainty of the problem lies in quantity of deliveries from suppliers. We apply three different strategies for the safety stock level and compare their efficiency through a rolling horizon planning simulation. The results will be illustrated for three cases; no safety stock, static safety stock and dynamic safety stock.

4 - Timber production on flammable forest landscapes

David Martell, Dennis Boychuk, Cristobal Pais, Andrés Weintraub, David Woodruff

We simulate forest and wildland fire spread on a spatial grid. Our simulator makes use of parallelism to allow scaling to large forests in which fires spread on a coarse grid or small forests on which smaller fires spread on fine-grained fire cells. Once a simulated fire is ignited in a cell, its stochastic spread to neighboring cells is simulated based on their characteristics, including the possibility that the cell has recently been harvested resulting in a modification of the fuel type. Fire spread rates are predicted using the Canadian Forest Fire Behaviour Prediction System. We consider two time scales, an annual one for lightning-caused fire ignition and an hourly for fire spread. A preliminary application to evaluation of spatially explicit timber harvest schedules is described.

■ TA-31

Tuesday, 8:30-10:00 - 304B

Teaching OR/MS 1

Stream: Teaching OR
Invited session
Chair: Laura Plazola Zamora

1 - Project-oriented OR courses for production planning

Pedro Piñeyro, Hector Cancela, Antonio Mauttone, Luis Stábile, Carlos Testuri

The Production Engineering degree is a novel offer at the Engineering School at the Universidad de la República in Uruguay. One of the distinctive aspects of this career is that it aims for students to have an early approach to production problems arising in real-life situations. In this sense, the curriculum includes in the fourth and sixth semester two related OR courses that employ a project-oriented learning methodology. Both courses consist of a first part of lectures and then a second part for addressing a practical problem through teamwork. During the first course, each group of students must look for and find a real-life situation and apply modeling concepts. This activity represents an important challenge for the students, as they must be able to identify a problem in their environment and establish a dialogue with the respective decision makers. At the end of the first course, each group of students presents the problem and its mathematical programming formulation. The formulation is then taken as input for the second course, where the goal is to provide a numerical solution through optimization, validate the solution with respect to the problem, and perform a brief sensitivity analysis. As teachers of the courses we have observed that students get very engaged with their work, are highly motivated, support their positions with well founded arguments and learn from the problem environment, which go beyond the strict content of the course.

2 - A case-based undergraduate operations research course

Daniel Frances, Daria Terekhov

This paper describes a purely case-based undergraduate course focusing on operations research that has been successfully run in the Industrial Engineering program at the University of Toronto for ten years. We describe the structure of the course, including the process adopted for solving the weekly cases, student assessment methods, and the choice of cases. Student feedback suggests that the course enhances the student learning experience through the principle of learning by doing, provides a platform for integration of operations research methods learned in earlier classes, can be conducive to improving communication skills, and addresses the gap between theory and practice through a simulated workplace environment.

3 - Comics as a tool for teaching and learning OR

Laura Plazola Zamora, Ana Torres

In this work we propose the use of comics as a teaching-learning strategy in the field of Operations Research in order to achieve a meaningful learning of the thematic content of this subject, as well as to encourage the creativity of marketing and business students of the Center of Economics and Administrative Sciences of the University of Guadalajara. The students used an application called POWTOON, to create animated videos and content presentations. These tools are useful in collaborative learning activities, such as alternative assessment, or even for students to create content for the class and thus increase their academic performance. Students stated that using these tools is a good way to present, explain, and describe ideas and concepts, cartoons turned out to be an alternative and fun way to achieve learning objectives.

Tuesday, 10:30-12:00

■ TB-01

Tuesday, 10:30-12:00 - 307B

Large-scale optimization in logistics and transportation

Stream: Discrete optimization in logistics and transportation

Invited session

Chair: *Sanjay Dominik Jena*

1 - On the spatial separability of uncapacitated single assignment p-hub median problems

Taghi Khaniyev, Samir Elhedhli, Fatih Safa Erenay

The spatial separability property of uncapacitated single assignment p-hub median problems (USApHMP) is studied. We illustrate that the optimal solutions to the well-known USApHMP instances can be partitioned into p allocation clusters, defined as the set of nodes which are allocated to the same hub, such that the convex hulls of the allocation clusters are disjoint. To exploit this property, a MILP formulation (USApHPP) for the problem of finding optimal hub locations for a given partitioning of nodes is introduced. Instead of enumerating all possible partitions which hold this property, a data driven approach to group the network nodes into regions and to obtain quality partitions based on the solution of a smaller (low resolution) USApHMP is proposed. Finally, the decomposable structure of the proposed USApHPP formulation is exploited to obtain tight lower bounds and to reduce computation time. Experiments on the largest problem instances available in the literature corroborate the effectiveness of the proposed approach in generating high quality solutions within a reasonable amount of time. We conclude that with certain improvements, the proposed approach has the potential to efficiently tackle problem instances larger than those currently available in the literature.

2 - A branch-and-Benders cut algorithm for the capacitated vehicle routing problem

Furkan Enderer, Claudio Contardo, Bernard Gendron

In this article, we introduce a new scheme to transform non-robust valid inequalities into robust Set-Partitioning based cuts by Benders Decomposition. The approach consists of reformulating the problem using redundant variables, and then using Benders decomposition to transform the problem into a cutting planes algorithm providing dual bounds provably equal to the one obtained by adding non-robust valid inequalities. We apply the new decomposition scheme to the Capacitated Vehicle Routing Problem and discuss several variations of the algorithm. Computational results on benchmark instances are reported and future research is discussed.

3 - The value of flexibility in long-haul transportation network design

Mike Hewitt

Freight transportation carriers are facing increased demands from customers for shorter service standards. At the same time, some customers are flexible in terms of when they want their shipments delivered, and will accept longer delivery times if given a discount. In this talk we present a new problem, the Service Network Design with Soft Time Windows Problem, that will not only design a long-haul transportation network, but will do so while also determining which customers to offer a discount to in order to have more time for delivery. We present a solution approach for the model and the results of an extensive computational study. In this study we consider the following questions: (1) How much can a carrier save by negotiating flexibility with its customers? (2) How many customers need to be flexible for a carrier to realize savings? (3) What attributes (e.g. shipment size, service standard) should a carrier focus on when determining which customers to negotiate flexible time windows? and (4) How flexible do customers need to be for a carrier to realize savings? In this talk we will present answers to each of these questions.

4 - A Lagrangian heuristic for a rapid transit line design problem
Souhaïla El Filali, Bernard Gendron, Gilbert Laporte

We propose a tight formulation for the rapid transit line design problem, which consists of locating stations and segments between them to form a line, with the objective of maximizing O-D pairs coverage under topological and budget constraints. We develop a Lagrangian heuristic to solve the problem, and we test it on artificial and real-life instances.

■ TB-02

Tuesday, 10:30-12:00 - 308B

Novel theoretical developments for integrated planning approaches

Stream: Design and management of manufacturing systems
Invited session
Chair: Alena Otto

1 - Theoretical foundation of iterative production planning - scheduling algorithms: The case of order release planning
Hubert Missbauer

Manufacturing planning and control systems usually exhibit a hierarchical structure. This requires an anticipation function that anticipates the behavior of the outcomes of the lower (base) level decisions when determining the decisions at the upper (top) level(s). Considering the scheduling level within the production units as the base level, production planning decisions that set the targets for the production units usually require parameters whose values result from the scheduling decisions. Dealing specifically with order release planning with load-dependent lead times, the planning model requires work center capacities and lead times as parameters that are difficult to anticipate. Therefore, order release planning algorithms have been developed that estimate load-dependent lead times and optimize order releases by iterating between a release model with fixed lead times and a simulation or queueing model that represents the scheduling level and updates the lead times. These algorithms often do not converge and thus do not provide a feasible solution. We present an analysis of the theory behind this iterative mechanism. We prove analytically that this mechanism is a defective application of Lagrangian techniques and suffers from fundamental problems. We show that convergence to the optimum cannot be expected and resolving this problem is not straightforward. Iterating on the capacities changes the theoretical basis and might contribute to a solution.

2 - A capacity planning MILP model including capacity allocation, backlogging, workforce planning, overtime and shift planning
Gorkem Yilmaz

Aggregate planning (tactical capacity planning) is the process of determining the production capacity needed to meet the final orders by deciding optimal levels of inventory on hand, production rate and workforce level over a given finite planning horizon. We develop a mixed integer linear programming (MILP) model to solve a variant of an aggregate production planning problem. The following characteristics are included in the problem: (1) capacity allocation: multi products and parallel production capacity planning and allocation problem over a finite planning horizon with deterministic demand is considered; (2) backlogging: due to production capacity restrictions, in the case that demand cannot be fulfilled before due date, backlogging is permitted by a given penalty costs; (3) overtime and shift planning: certain amount of overtime can be allowed and depending of workload of a given period, number of shifts can be increased or decreased; (4) workforce planning: number of the workers to be hired or fired in a certain period is given at the beginning of each period. The computational efficiency of the proposed model formulation is investigated by randomly generated instances. According to the results, the suggested model can be considered as an appropriate tool to deal with this kind of problem.

3 - Effective continuous-time formulations for scheduling shipyard block assembly system
Natalia Paola Basán, Javier Faulin, Alejandro García del Valle, Mendez Carlos

The strong global competition in the shipbuilding market forces the shipyards to focus their efforts on providing reliable products of high quality, with minimum processing and assembly times, and better utilization of critical system resources. Therefore, the development of efficient medium-term and short-term operations strategies in the assembly processes of blocks becomes a potential alternative to achieve greater competitiveness. The present work aims at finding out the optimal solution of production and assembly operations in a system of multi-stage production of ships of a shipyard while all constraints are satisfied. A ship manufacturing system, which involves a series of production and assembly processes of block and sub-block for large-scale shipbuilding is considered. Hence, two new mixed integer linear mathematical formulations (MILP) are proposed to solve the scheduling problem aiming at minimizing the total processing and assembly time of blocks and sub-blocks (makespan) in the yard: (i) a MILP model based on the continuous time-slot concepts, and (ii) a MILP model based on precedence continuous-time concept. The mathematical formulation based on precedence of continuous conception of time, requires a smaller number of decision variables and, at the same time, allows obtaining efficient solutions to academic problems with a reasonable computational effort. Both MILP formulations were tested and computational experiences were reported for real world problems.

4 - Single machine scheduling with combined time-changing effects
Vitaly Strusevich, Kabir Rustogi

We consider single machine scheduling problems in which the actual processing times of jobs are subject to various effects. We mainly focus on combined effects that involve a positional effect and either a start-time dependent effect or a cumulative effect. The objectives functions to be minimized include the makespan and the total completion time. The problems of this range have been addressed in our recent book "Scheduling with Times-Changing Effects and Rate-Modifying Activities" (Springer, 2016). We present the most general conditions of the functions that define the combined effects which allow finding the corresponding optimal sequence in polynomial time, including by simple priority rules. Typically, such conditions include convexity/concavity and/or monotonicity of the corresponding functions. This allows handling most problems in this area by very similar techniques, and most previously known results can be derived from our general framework. The problems that involve effects that do not satisfy our conditions are shown not to be solvable by priority rules and in fact their complexity status remains open.

■ TB-03

Tuesday, 10:30-12:00 - 200AB

Keynote speaker: Stefania Bellavia

Stream: Keynote sessions
Keynote session
Chair: José Mario Martínez

1 - Computational aspects in second order methods for large scale optimization
Stefania Bellavia

In the recent years interest kept on steadily increasing around second order methods for the resolution of continuous large scale problems traditionally handled by first order methods. This has been the case for example for machine learning and compressed sensing problems. In this tutorial, we will analyze key computational aspects related to an efficient implementation of second order methods for large scale problems. In particular we will focus on Newton-like methods for different classes of problems (nonlinear least-squares, linear programming, semidefinite programming) and we will discuss how the arising large scale Newton equations can be efficiently handled by iterative linear solvers. We will analyze the level of error acceptable in the Newton equations so to keep the favorable convergence properties of Newton-like methods and how to speed up the adopted iterative linear solver. We will show that careful use of second-order information and proper use of the problem's structure can lead to very efficient optimization methods, which significantly overpass their potential cost limitations.

■ TB-04

Tuesday, 10:30-12:00 - 202

Location, logistics, transportation and traffic 2

Stream: Location, logistics, transportation, traffic (contributed)
Contributed session
Chair: Lakshay .

1 - A study of dispatch frequency for a city logistics provider
Che-Fu Hsueh

E-commerce has grown rapidly in recent years, and delivery speed has become a critical competitiveness for E-commerce companies and logistics providers. Some companies increase their dispatch frequency from once a day to twice a day or even higher. Amazon Prime Now can deliver selected items to their customers within two hours. Different dispatch frequencies result in different costs and demands, as well as different kinds of vehicles used. The higher dispatch frequency means more drivers, smaller vehicles, and less waiting times. This paper analyzed factors that affect the dispatch frequency, and proposed a simulation algorithm to determine the optimal dispatch frequency. Time-dependent demands are generated repeatedly in the simulation based on the historical information. Given the generated demands, a bi-level optimization model is solved using the proposed heuristics algorithm. The decision variables in the upper-level model are dispatch frequencies and products grouping, while the lower-level model is a vehicle routing problem with heterogeneous fleets. The simulation results show that higher dispatch frequency may cause longer travel distance, but does not necessarily result in higher costs. The product groups with high waiting costs should be delivered more frequently. Environment-friendly and low-capacity vehicles, such as electric motorcycles, bicycles, or even drones, are suggested for being used in city logistics with high dispatch frequency.

2 - Robust traffic management for the Kiel canal
Frank Meisel

The Kiel Canal is an artificial waterway that connects the Baltic Sea and the North Sea. It allows ships to save about 250 nautical miles compared with traveling around the Jutland Peninsula (Denmark). Unfortunately, the canal consists of several narrow transit segments where large ships cannot pass each other. The passing of ships of any size is possible in so-called sidings, which are widened segments of the canal. The purpose of the traffic management is to decide on the ships that have to wait in a siding in order to avoid conflicts in the transit segments. The decisions affect the transit times of ships and, thus, have an impact on the attractiveness for ship operators to send their vessels through the canal rather than going around Jutland. There has been prior research on this traffic management problem in a deterministic setting. In our presentation, we extend the setting by stochastic travel times of ships and stochastic exit times when ships leave the locks and enter the canal. Various priority rules are used to produce conflict-free ship schedules of low average transit times for the deterministic setting. We then test the robustness of these schedules by checking whether the waiting decisions remain feasible under a given set of scenarios for travel times and exit times. It is shown by experiment that robust solutions require just slightly larger average transit times.

3 - Self-organisation in traffic signal control algorithms
Samantha Movius

Two popular types of traffic signal control are fixed-time control and vehicle-actuated control. The latter method involves switching traffic signals based on detected traffic flows and thus offers more flexibility than the former, which relies solely on cyclic, predetermined signal phases. The notion of self-organisation has relatively recently been proposed as an alternative approach towards improving traffic signal control, due to its flexible nature and its potential to result in emergent behaviour. The effectiveness of five self-organising traffic signal control strategies from the literature are compared in a newly designed agent-based, microscopic traffic simulation model. Various shortcomings of three of these algorithms are identified and algorithmic improvements are suggested to remedy these deficiencies. The significant improvements resulting from these algorithmic modifications are then quantified. Furthermore, two new self-organising algorithms are also proposed in which the shortcomings discovered in the other five algorithms are addressed. These seven algorithms are subjected to thorough testing in the aforementioned simulation framework in terms of their propensity to facilitate the formation of green waves of traffic flow within the context of both gridded street networks and corridors with approaching side roads under light and heavy traffic conditions.

4 - Operating strategies for bus-based evacuation planning
Lakshay ., Nomesh Bolia

This study develops a bus-based evacuation planning scheme for disasters that occur with little advance warning. The objective is to evacuate all transit-dependent endangered people within available time, in case a disaster occurs. Due to high demand and limited resources, the focus is on developing optimal bus operating strategies to utilize the available resources efficiently. The operating strategies involve finding the total number of trips across all buses and their respective sequence to achieve the given objective. Mixed integer time-indexed linear programming models have been formulated to develop these strategies. One of the models helps emergency managers in strategic planning by finding the minimum number of buses that must be available at respective depots to achieve the target evacuation time. Another model is developed to identify the detailed sequence of trips and their respective routes to be followed for a given evacuation scenario. To test the efficacy of the developed models, a case study is presented in which evacuation is required due to occurrence of a nuclear accident. The results indicate that the model can be used by emergency managers (even before the occurrence of event) to develop an evacuation plan for a transit dependent population. Further, uncertainty in terms of breakdown of available buses and available time has also been incorporated.

■ TB-05

Tuesday, 10:30-12:00 - 203

Stochastic modeling and simulation in engineering, management and science 1

Stream: Stochastic modeling and simulation in engineering, management and science
Invited session
Chair: *Erik Kropat*

Chair: *Zeev (Vladimir) Volkovich*
Chair: *Gerhard-Wilhelm Weber*
Chair: *Ronald Akerman Ortiz Garcia*

1 - "Dice"-sion making under uncertainty: When can a random decision reduce risk?
Erick Delage, Daniel Kuhn, Wolfram Wiesemann

Consider an Ellsberg experiment in which one can win by calling the color (red or blue) of the ball that will be drawn from an urn in which the two colored balls are of unknown proportions. It is actually well known (yet rarely advertised) that delegating the selection of the color to a fair sided coin can completely eradicate the ambiguity about the odds of winning hence has the potential of reducing the amount of perceived risk. In this talk, we explore what are conditions under which a decision maker that employs a risk measure should have his action depend on the outcome of a random device such as a coin or a dice. We find that in the absence of distributional ambiguity, deterministic decisions are optimal if both the risk measure and the feasible region are convex, or alternatively if the risk measure is mixture-quasiconcave. Several classes of risk measures, such as mean (semi-)deviation and mean (semi-)moment measures, fail to be mixture-quasiconcave and can therefore give rise to problems in which the decision maker might benefit from a randomizated policy. Under distributional ambiguity, on the other hand, we show that for any ambiguity averse risk measure there always exists a decision problem (with a non-convex, e.g., mixed-integer, feasible region) in which a randomized decision strictly dominates all deterministic decisions.

2 - Demand management for distribution centers: Does stochastic variability matter?
Raik Stolletz, Axel Franz

Demand management aim at smoothing demand by shifting arrivals from peak to off-peak periods in order to improve the system's operational performance. We analyze truck arrivals at distribution centers for air cargo. Such systems are characterized by time-dependent truck arrivals. The demand is of stochastic nature for both the arrival process and the handling capacity. We model that system as a time-dependent multi-server queue with heterogeneous classes of trucks and generally distributed inter-arrival and processing times. We present a decision model to smooth the demand while minimizing the expected waiting time. Decision variables are related to changes in the original demand pattern. They are limited and penalized. We provide a reliable and fast methodology to evaluate and optimize the arrival pattern. We develop a stationary backlog-carryover approach for this heterogeneous queueing model with general distributions. The respective non-linear optimization model could be solved numerically. A numerical study compares the performance measures of original and optimized arrival patterns. The impact of stochastic variability on the solution is shown. For real data from a cargo center of a large European airline we shows that a significant reduction in waiting times can be reached even with minor shifts in time-dependent arrival rates.

3 - Representation of the Uncertainty Scenarios in the Brazilian Hydrothermal Dispatch: Replacement of Inflow Tree by Lattice
Fernanda Nakano Kazama, Laura Silva Granada, Paulo Correia

We can use trees and lattices to represent scenarios of uncertainty in dynamic and stochastic problems. Trees are used when the scenarios are path dependent while lattice are used when they are path independent. The number of paths of a tree is equivalent to the number of leaves and they increase exponentially with the raise of the number of stages analyzed. On the other hand, the number of terminal nodes of a lattice increases linearly while still maintain the exponential growth of paths. In this way, the lattice can present the same number of scenarios of a tree with a more compact structure reducing the computational effort to solve the problems. Trees are used nowadays in Brazil to represent the inflows scenarios in the hydrothermal dispatch problem, but since Brazil has hydroelectrics with large capacity for storing water in its reservoirs it is indifferent if in a month it rains a lot and in the other it rains a little or the reverse. So it is believed that it is possible to replace the inflow tree by a lattice in the Brazilian hydrothermal dispatch optimization. As a way to test the viability of this replacement it will be presented a case study based in Tocantins basin data. Comparing the results of the two methods it is possible to conclude that they match and the proposed method requires less computational effort, so it is possible to replace the inflow tree for lattice in this case and it allows to solve the problem for longer periods.

4 - A rumor spreading based evacuation simulation model in call center environments: A case study in Medellín, Colombia
Ronald Akerman Ortiz Garcia, Yony Fernando Ceballos, Elena Valentina Gutiérrez

During emergency events in working environments is complex to identify how people will behave. Call centers are usually crowded working environments, and therefore in such companies evacuation plans are particularly important, in order to assure employees safety. Previous works in the literature show a set of efforts to model people behavior in emergency events with the aim to improve evacuation plans. Moreover, it has been identified that people physical and psychological traits influence on evacuation plans performance, and therefore cooperation and competition situations can be generated. Rumor spreading is an appropriate approach that allows to model people behavior in emergency events because they include characteristics as propagation and reaction velocity. In this work, we propose an agent based simulation model that uses rumor spreading in order to evaluate the effect of different emergency polices on evacuation performance measures. The model is validated in a real call center in Medellín, Colombia. Results show that how physical and psychological traits influence on the effectivity of evacuations plans, using local legal regulation.

■ TB-06

Tuesday, 10:30-12:00 - 204A

HCOR healthcare SIG student presentation competition

Stream: CORS student paper competitions
Award Competition session
Chair: *Nadia Lahrichi*
Chair: *Armann Ingolfsson*
Chair: *David Stanford*
Chair: *Valérie Bélanger*

■ TB-07

Tuesday, 10:30-12:00 - 204B

Routing and scheduling in urban logistics

Stream: Vehicle routing
Invited session
Chair: *Vera Hemmelmayr*
Chair: *Pamela Nolz*
Chair: *Benjamin Biesinger*

1 - Strategic planning of free-floating electric car sharing systems with user incentives
Benjamin Biesinger, Bin Hu, Martin Stubenschrott, Matthias Prandtstetter

Urban car sharing systems as addition to public transport gained much attention recently. Especially when operated with battery electric vehicles such systems can reduce local emissions, air pollution, and contribute towards a sustainable city. In order to be successful, these systems have to be carefully planned and several strategic decisions have to be made. We consider the planning of a free-floating electric car sharing system regarding the strategic decisions of the operator. Compared to station-based systems, in a free-floating environment the users can rent and return the cars anywhere within the operational area. When using electric cars, however, recharging stations have to be planned. The problem of how many and where to place these stations and the optimal number of cars to be deployed is modeled as a combinatorial optimization problem. The quality assessment of these decisions is performed by simulating users of the system based on a demand and behavior model. The latter is based on a probability model for the user decisions to approximate the expected profit of the system. A major challenge is to find a realistic correlation between incentives and the probability of relocating stranded cars by users or returning the car at a nearby station instead of the actual desired destination. We show that our simulation-based model is more realistic than other straightforward optimization models in the literature and that the results approximate real-world systems well.

2 - Location flexibility in parcel delivery services

G.D.H. (Frits) Claassen, Dmitry Krushinsky, Xuezhen Guo

Due to the growth of e-commerce, the demand and market for parcel delivery services is exploding. In 2013, the largest parcel delivery service in the Netherlands delivered about 131 million parcels. In 2014, the parcel delivery market already increased by more than 45% in the Netherlands. Consequently, the competition in this market is fierce and consumers become more and more in control. Selling arguments like "Ordered before 11:00 PM will be delivered the next day", are hardly an exception. In order to compete with competitors, couriers have to be faster and delivery rates must increase. Simultaneously, customers are often not at home at delivery moments and less parcels are delivered according to customers' expectations. We present an innovative approach for improving a one-to-many transportation system for parcel delivery services. The improved efficiency applies to both the courier and the customers. The concept is based on alternative delivery locations. Two possible scenarios are proposed. Although route optimisation behind both scenarios is closely related to the Generalised TSP, some adjustments to the model and the solution method are needed. Results of extensive computational experiments with real-world data are presented to justify the potentials of the proposed approach.

3 - Operational plannings of couriers for attended home delivery

Frédéric Semet, Luce Brotcorne, Maria-Isabel Restrepo, Thomas Pocreau

Attended home delivery is a last-mile delivery service, where the customer must be present for the delivery. The classical delivery model utilizes couriers who serve customer requests. Most of couriers have short-duration delivery routes with respect to the planning horizon. In this presentation, we address an integrated shift scheduling and load assignment optimization problem for attended home delivery. The proposed approach is divided into two phases, each one corresponding to a different planning level : tactical and operational. In the tactical planning, a daily master plan is generated for each courier. More precisely, we define a tactical problem as an integrated shift scheduling and load assignment problem under demand uncertainty, which is modeled as a two-stage stochastic programming model. To solve this problem, we develop a multi-cut integer L-shaped algorithm. In the operational planning, delivery orders are allocated to couriers in real-time. The proposed approach relies on the generation of delivery routes, which are based on the o-d pairs assigned in the tactical planning phase. Results on real-world based instances demonstrate that our approach provides robust tactical solutions that easily accommodate to fluctuations in customer orders.

■ TB-08

Tuesday, 10:30-12:00 - 205A

Revenue management: From theory to practice

Stream: Revenue management and pricing
Invited session
Chair: Kerstin Schmidt

1 - An exact method to solve the challenging sales based integer program of airlines revenue management

Mauro Piacentini, Gianmaria Leo, Giorgio Grani, Laura Palagi, Hunkar Toyoglu

Revenue Management (RM) has been playing over recent years an increasingly crucial role in both strategic and tactical decisions of Airlines business. Successful RM processes aim to achieve the maximization of revenue by leveraging huge amount of data, upcoming technologies and more sophisticated approaches to measure the RM performances. This leads top carriers to invest millions of dollars every year to face the challenge of catching new revenue opportunities. Multiple phases of RM processes, as well as different components of RM systems, are based on the solution of large integer programming models, like the well-known Sales Based Integer Program (SBIP), whose instances turn out to be challenging, or even not solvable in practice by the state-of-art MIP solvers. Our work aims to investigate useful polyhedral properties and introduce a practical exact method to solve hard instances of SBIP. Firstly, we strengthen the linear relaxations of subproblems generated in LP-based branch-and-bound paradigm by introducing effective Chvátal-Gomory cuts, inspired by the polytope. As a major result, we investigate a Benders-like decomposition leading to an exact cost-effective method. Main idea is to optimally allocate the capacity to the markets by transforming the market subproblems into a piecewise linear objective function. Main advantages are significant reduction of the problem size and the possibility of deriving a concave objective function which is strengthened dynamically.

2 - Overbooking under dynamic and static policies for network

Wei Wang, Ravi Kumar, Darius Walczak

Overbooking and cancellation are important aspects of revenue management, and much research including dynamic programming-based solutions is available in the literature. However, in practice airlines today are still applying static approaches. As an extension to our previous work for single leg, we present a simulation-based comparison of different models under both dynamic and static policies on the network, in particular we allow both no-show refund and cancellations refund to be class dependent.

3 - Revenue management approach for two-way e-carsharing systems with one electric vehicle

Kerstin Schmidt, Isa von Hoesslin, Thomas Volling, Thomas Spengler

We consider a decision support system for the efficient acceptance of customer requests in two-way e-carsharing systems with one electric vehicle. Special challenges arise from the limited and perishable availability of the electric vehicle in combination with a second limited but also storable capacity with dynamic replenishment - the rechargeable battery load of the electric vehicle. For each incoming customer request the e-carsharing operator has to decide whether to accept the request in consideration of intertemporal interdependencies. Intertemporal interdependencies arise between customer requests due to different user profiles depending on start and length of booking as well as energy consumption. To address these characteristics, we develop a new revenue management approach by modeling the dynamic program for two-way e-carsharing systems and present a certainty equivalent control as approximation. The performance of the proposed approach in comparison to a first-come, first-served approach and an ex-post optimal solution is evaluated in a simulation study. The proposed approach outperforms the first-come, first-served approach by 5.25 % in the reference setting

■ TB-09

Tuesday, 10:30-12:00 - 205B

IFORS: Past, present and future

Stream: IFORS sessions
Panel session
Chair: Graham Rand

1 - IFORS: Past, present and future
Peter Bell, William Pierskalla, Elise del Rosario, Michael Trick

This session will first consider the creation of IFORS in 1959, following the first international OR Conference, held sixty years ago in Oxford (Graham Rand). Then three former presidents (Bill Pierskalla, 1989-91, Peter Bell, 1995-97, and Elise del Rosario, 2007-09) will reflect on their years of service to IFORS, before the current president, Mike Trick looks at the challenges facing IFORS.

■ TB-10

Tuesday, 10:30-12:00 - 205C

Bilevel and two-phase optimization approaches

Stream: Multiobjective optimization methods and applications
Invited session
Chair: Pekka Malo

1 - Multi-objective Stackelberg game between a regulating authority and a mining company: A case study in environmental economics
Anton Frantsev, Ankur Sinha, Pekka Malo, Kalyanmoy Deb

Bilevel programming problems are often found in practice. In this paper, we handle one such bilevel application problem from the domain of environmental economics. The problem is a Stakelberg game with multiple objectives at the upper level, and a single objective at the lower level. The leader in this case is the regulating authority, and it tries to maximize its total tax revenue over multiple periods while trying to minimize the environmental damages caused by a mining company. The follower is the mining company whose sole objective is to maximize its total profit over multiple periods under the limitations set by the leader. The solution to the model contains the optimal taxation and extraction decisions to be made by the players in each of the time periods. We construct a simplistic model for the Stackelberg game and provide an analytical solution to the problem. Thereafter, the model is extended to incorporate realism and is solved using a bilevel evolutionary algorithm capable of handling multiple objectives.

2 - Aubin property for solution mapping in parametric linear programming problem
Daniil Berezhnov, Leonid Minchenko

Lipschitz-like properties of solution mappings in parametric optimization problems play an important role in sensitivity analysis and in the investigations of bilevel programs. Our paper discusses conditions for the Aubin property of solution mappings to perturbed mathematical programs under the Mangasarian-Fromovitz constraint qualification. We prove that the inner semi-continuity of a solution mapping at a given point implies that the Aubin property holds at this point. Moreover, we prove that the solution mapping has the Aubin property at a given point if it is uniformly bounded and single-valued at this point.

3 - A bi-objective GRASP with path relinking to optimize waste collection services: A practical application in the south of Spain
Laura Delgado Antequera, Manuel Laguna, Joaquín Pacheco, Rafael Caballero

Effective solutions to problems in logistics must balance several types of benefits associated with cost reduction, service improvement, and infrastructure and equipment utilization. The search for improved decisions results in the need to optimize conflicting objectives within a search space defined by the problem's constraints. In the particular area of waste collection services, companies invest a great deal of effort to provide superior service while taking into consideration financial, social, labor, and environmental factors. In this work, we consider a problem with two objectives: 1) minimization of the total travel cost and 2) balancing of the routes. The resulting bi-objective optimization problem is tackled with a two-phase procedure. The first phase uses GRASP constructions to generate a set of feasible solutions. In the second phase, each pair of solutions is used to launch a path-relinking search. The set of non-dominated solutions found throughout the construction process and the path-relinking search is returned as the best approximation of the Pareto front. The effectiveness of the approach, as measured by its ability to produce high-quality solutions in a reasonable amount of time, is tested using data from a waste collection problem in a southern region of Spain.

4 - Solving optimistic bilevel programs by iteratively approximating lower level optimal value function
Pekka Malo, Ankur Sinha, Kalyanmoy Deb

Bilevel optimization is a nested optimization problem that contains one optimization task as a constraint to another optimization task. Owing to enormous applications that are bilevel in nature, these problems have received attention from mathematical programming as well as evolutionary optimization community. However, most of the available solution methods can either be applied to highly restrictive class of problems, or are highly computationally expensive that they do not scale for large scale bilevel problems. The difficulties in bilevel programming arise primarily from the nested structure of the problem. In this paper, we propose a metamodeling based solution strategy that attempts to iteratively approximate the optimal lower level value function. To the best knowledge of the authors, this kind of a strategy has not been used to solve bilevel optimization problems, particularly in the context of evolutionary computation. The proposed method has been evaluated on a number of test problems from the literature.

■ TB-11

Tuesday, 10:30-12:00 - 206A

Hyperheuristics

Stream: Hyperheuristics
Invited session
Chair: Andrew J. Parkes

1 - A hyperheuristic framework for optimizing the parameters of dual local search
Mona Hamid, Jamal Ouenniche

Combinatorial optimization problems have been at the origin of the design of many optimal and heuristic solution frameworks such as branch-and-bound algorithms, branch-and-cut algorithms, classical local search methods, metaheuristics, and hyperheuristics. In this paper, we propose a hyperheuristic framework to optimize the parameters of a generic and parametrised dual local search algorithm with application in routing. Empirical results suggest that the proposed framework delivers outstanding performance.

2 - Combining particle swarm optimization variants on high dimensional continuous optimization problems
Hugo Deschênes, Caroline Gagne

The particle swarm optimization is a well-known metaheuristic that has been proven useful in solving continuous optimization problems. Many variants have been elaborated in the literature, hoping to enhance the exploitation and the exploration of the space search. Even if this method has been improved among the years, it has however demonstrated difficulties in solving high dimensional problems. One interesting idea to balance this weakness is to combine forces of several metaheuristics by putting each one's particular advantages up front. Considering these facts, this research presents five hybridizations based on three particle swarm optimization variants: the barebones particle swarm optimization, the comprehensive learning particle swarm optimization, and the cooperative learning particle swarm optimization. Each one of them has been proven efficient in the literature and adopts a different behavior in solving optimization problems. The goal of this research is to outperform the other methods listed above and balance the main weakness of the particle swarm optimization, which is of obtaining good results on high-dimensional problems. The comparison between the hybrids is done using stochastic dominance and convergence analysis. The results show that hybridization between particle swarm optimization variants helps enhance the solutions obtained and improves considerably the results on high-dimensional continuous problems.

3 - Optimising LEGO constructions
Torkil Kollsker

Given any 3D layout, how can you build it with a set of LEGO bricks? Relatively few bricks open up for a colossal amount of possible brick combinations. Here we limit ourselves to consider a predefined outer shape made by a designer that also specifies which colours to use. The inner shape, on the other hand, can be constructed as desired as long as the construction is stable. There are several objectives to optimise in this problem: The structural stability, the cost of bricks and the aesthetics. Here we describe an approach to optimise LEGO constructions using metaheuristics. A prototype of the software has been developed, which provided stable constructions for small models. Other approaches in the literature have focused on Local Search algorithms, which we believe limits the search space significantly. Currently we are working on applying various advanced techniques in Operations Research to make the metaheuristic more efficient in order to apply it on larger models.

■ TB-12

Tuesday, 10:30-12:00 - 206B

Financial mathematics 4

Stream: Financial mathematics and OR
Invited session
Chair: Markku Kallio
Chair: *Gerhard-Wilhelm Weber*

1 - Portfolio optimization models considering behavioral stocks
Kuo-Hwa Chang, Michael Young

We study the portfolio optimization problem considering behavioral stocks that are affected by the collective irrational behaviors of investors. Based on statistics tests, we identify the behavioral stock by observing the epoch of the cause when its investors behave irrationally and the epoch when the effect on its price movement is recognized. Time between the cause and the effect and the likelihood of the effect are two important attributes of behavioral stocks and they are estimated. Accordingly, two mixed integer portfolio optimization models on these behavioral stocks are considered. One is used when the cause has been sensed and the other is for when the resulting positive effect on the behavioral stock is anticipated to take place. Numerical backtest results show that the corresponding portfolios considering behavioral stocks and utilizing their cause-and-effect information outperform the market and other benchmark portfolios significantly.

2 - Dynamic analysis of ridesharing markets in the presence of incentivized matching
Qi Wu, Shumin Ma

We study how incentives created by driver-targeted loyalty programs influence the dynamics of supply and demand across space and time. A ridesharing market is a tri-party system consisting drivers, passengers, and the company who provides the matching service. When supply and demand are not aligned, a loyalty program would work as a supply adjustment policy without suppressing the demand. Technically, we model matching in space through Stackelberg game, and establish dynamic equations governing the evaluation of conditional spatial-distributions of supply and demand. By making distinctions between steady-state and supply-demand equilibrium, and further characterizing the conditions to achieve them, we are able to analyze theoretically how incentives influence the evolution of this tri-party interacting system. What we find is that for a given number of available drivers in the system, how much "additional" supply could be created is capped by the maximum matching ratio, achieved at the optimal amount of incentives. Beyond that amount, matching ratio will decline. The business implication is that while the effect of supply multiplier allows a firm to enlarge its supply capacity in response to demand surge, incentivize excessively, however, would be disruptive. Spending further means money is not used to boost additional matching but is directly passed down to drivers as income.

3 - Cooperative mitigation of contagion in financial networks
Markku Kallio, Aien Khabazian

A typical financial network comprises multiple financial institutions interacting with each other through borrowing and lending or interconnecting indirectly through the market by holding similar portfolios. The presence of such linkages has various consequences in the financial market. For instance, whenever some institute bankrupts in the system, it may lead to a catastrophic disaster by spreading failures over the network. This is referred to as the systemic risk and it has prompted extensive studies on the sources and effects of the crises, and on tools to mitigate the systemic risk for an increased resilience of the financial network. Different from existing literature, our intention is to reveal the incentive among banks for collaboration to mitigate crises in financial networks. For this purpose, we examine the network as a co-operative game. The motivation arises from political trends, for instance, in the US and in the EU, which tend to prevent the use taxpayers' money to cover financial losses by banks in case of a banking crisis. Using field data, we show that it can be in the interest of banks to cooperate and prevent the domino effect which would hurt everyone. Of course, such cooperative decisions would be based on negotiations. Therefore, our aim only is to disclose attractive opportunities for negotiations among banks.

4 - A portfolio decision process with a value-at-risk criterion
Yuji Yoshida

A financial portfolio decision process with value-at-risks is discussed, and the risk criterion is composed by unexpected short-term risks which occur suddenly in each period. Analytical solutions for the value-at-risk portfolio problem are obtained at each period. By dynamic programming, we derive an optimality equation for the optimal value-at-risk in the decision process under a reasonable assumption, and an optimal trading strategy is obtained from the equation.

■ TB-13

Tuesday, 10:30-12:00 - 207

Personnel scheduling 2

Stream: Scheduling problems in logistics
Invited session
Chair: Guy Desaulniers

1 - Personnel shift scheduling with preferences in the retail industry
Lucas Bancel, Guy Desaulniers

In this talk, we investigate how to build shift schedules in the retail industry considering employees' preferences by order of seniority. Many types of preferences could be considered but we focus on working a maximum time per week. This problem is modeled as an integer program where various weights are attributed to the employees in the objective function. This model is solved using a heuristic that consists in solving the problem by groups of employees and fixing the schedules at each iteration. We will report results obtained try our model on real-life instances.

2 - Real-time personnel re-scheduling after a minor disruption
Issmail El Hallaoui, Rachid Hassani, Guy Desaulniers

We present an efficient and fast heuristic for re-optimizing in real time a personnel schedule after a minor disruption. This fast heuristic computes for a single disruption one or several good solutions to propose to the planner. It exploits the dual solution of the linear relaxation of the model used to compute the planned schedule. The heuristic uses a non-parametric regression method to estimate the evolution of some dual values when the planned schedule is subject to multiple disruptions, yielding hence a sequence of re-optimizations. Extensive computational experiments, performed on various instances derived from real-world data sets involving between 15 and 195 employees, show that the proposed heuristic finds in less than two seconds optimal solutions in more than 91% of the test cases.

3 - Re-scheduling employees to avoid overtime
Cherifa Saadi, Guy Desaulniers

In the service industry, personnel shift scheduling seeks to build work schedules for a set of employees in order to meet the customers' demand at the least cost. As planned, schedules are often modified during the operations, it often happens that the shifts of some employees are lengthen and some employees fall in overtime. At the end of the day, the schedules of those employees are often updated again to avoid overtime as much as possible. In this talk, we address this re-scheduling problem which is modeled as an integer program solved by a commercial MIP solver. We will report computational results obtained on instances derived from real-life data sets.

■ TB-14

Tuesday, 10:30-12:00 - 305

MCDA applications and new research directions 2

Stream: Multicriteria decision analysis
Invited session
Chair: Valentina Ferretti

1 - Designing decision maps: Subjective values in spatial analysis for policy-making processes
Giovanna Fancello

Urban and territorial planning and spatial multi-criteria evaluation need decision analysis methods able to understand and synthesize multiple information in space in order to be useful, meaningful and legitimated within policy-making processes. According to the capability approach and the theories about the "right to the city", individuals influence and are influenced by the context. So, the opportunities offered by the context can hardly be divorced from the values of different options people have to develop in a capability set. All these aspects are fundamental for the definition of decision maps that help in the design of public policies. In this sense, the research aims to define decision analysis methods that consider objective aspects but also subjective values, individual features and actions in space for the design of decision maps. Especially, the research inquires how to collect and analyse subjective and objective features useful for the policy cycle and how to synthesize them in space. Urban Quality of Life, Walkability and Urban Resilience are fields that we investigate as case studies for the development of new spatial analysis methods.

2 - Generation of alternatives within policy making processes
Irene Pluchinotta, Valentina Ferretti, Alexis Tsoukias

The design of alternatives is an essential part of decision making that has been neglected in theory and practice. Most scholar articles in Decision Analysis and Operational Research introduce a problem formulation that starts with the claim "given a set A of alternatives". Both researchers and practitioners know that in reality the set A of alternatives is rarely "given". It is rather constructed during the decision aiding process and, most of the times, (re)defined several times during that same process. This topic, surprisingly ignored in the specialist literature, is particularly relevant in the context of public policy making. Within the policy-making process or "policy cycle" (i.e. issue identification, objectives definition, design, testing, finalization, implementation, monitoring and evaluation, readjustment), policy design represents a crucial phase since it has a preponderant impact on the quality of the policy alternatives being considered. This talk addresses the question of how the generation of policy alternatives can lead to innovation within a decision aiding process for policy making. By innovation in decision aiding we mean the mechanism that allows to expand the solution space and discover new alternatives to solve the problem under consideration. The talk is based on two real case experiences from Southern Italy: a planning problem in a UNESCO site and a groundwater management and protection policy issue

3 - Roles of multicriteria decision analysis in public sector strategic planning
Theodor Stewart

The concepts developed in this presentation arose in the context of national energy planning in developing countries, taking into consideration reaction to and mitigation of climate change. The concepts apply equally to other strategic natural resource planning problems. We identify three phases in such strategic planning processes: an initial identification of courses of action that can be implemented; an assembly of such actions into portfolios that constitute potential policies; and the evaluation of such policies to provide final recommendations. Each phase can be viewed as a multiple criteria decision making problem, but different MCDA mechanisms will be appropriate to each. The first has a strong problem structuring element and discrete choice MCDA applied to a sorting problematique. The second is a multiobjective portfolio optimization problem, with the aim of generating a short-list for final consideration, within which we apply multiple reference point approaches. The third phase is again a discrete choice problem aimed at choice or ranking of alternatives, often in the presence of important qualitative criteria. We shall trace the development and integration of MCDA thinking through these three phases, and the need for back-tracking at times to earlier phases. The approach will be illustrated by reference to earlier work in water resources planning, with some hypothetical extensions to create a clear numerical example

4 - Fuzzy extension of the outranking based rough set approach
Salem Chakhar, M Reza Abdi, Ashraf Labib, Mariem Masmoudi, Habib Chabchoub

The Outranking based Rough Set Approach (ORSA) is new ordinal classification method that maintains the foundations of the Dominance-based Rough Set Approach (DRSA) whilst allowing the use of criteria weights. In addition to the support of criteria weighting, the ORSA differs from the DRSA with respect to two main aspects. First, it relies on an outranking relation - instead of the dominance relation used in the DRSA - offering thus a flexible tool to model the preferences of decision maker by supporting the non-transitivity of indifference and incomparability situations. Second, it uses a different interpretation of decision rules, which are now mimicking the limiting profiles between unions of decision classes in a similar way to the concept of limiting profiles between ordered categories in the ELECTRE TRI method. The objective of this paper is to introduce the theoretical foundation of the Fuzzy ORSA, as an extension of ORSA in order to capture the fuzziness of real-world applications. More specifically, in this paper, we first extend the basic concepts of the Fuzzy ORSA, including a new fuzzy outranking relation, an extended definition of the upward and downward unions of fuzzy decision classes and the computing of the lower and upper approximations of these unions of classes. Then, we present a set of algorithms for the inference of fuzzy decision rules and a series of assignment procedures for exploiting these rules.

■ TB-15

Tuesday, 10:30-12:00 - 307A

Methods and algorithms in convex optimization 2

Stream: Continuous optimization (contributed)
Contributed session
Chair: Matus Benko

1 - A linear-time algorithm for computing conjugates of piecewise linear-quadratic functions
Yves Lucet, Tasnuva Haque

Computational convex analysis focuses on the efficient computation of fundamental convex transforms, most notably the Legendre-Fenchel transform. Efficient algorithms have been implemented in the CCA numerical library that computes the entire graph of such transforms. A major challenge is to extend those algorithms to piecewise-defined functions whose domains do not follow a grid structure. We will summarize two previous algorithms based on computational geometry and parametric programming that run in log-linear time. Then we will present a new algorithm that combines a neighborhood graph with graph-matrix calculus to achieve a linear-time worst-case complexity.

2 - Fast subgradient method with dynamic smoothness parameter
Enrico Gorgone, Antonio Frangioni, Bernard Gendron

We present and computationally evaluate a variant of the fast subgradient method of [Nesterov, 2005] that is capable of exploiting information, even if approximate, about the optimal value of the problem. This information is available in some applications, among which the computation of bounds for hard Integer Programs. We exploit the information to dynamically change the critical smoothness parameter of the algorithm, showing that this results in a better convergence profile of the algorithm.

3 - Sequential injective algorithm for weakly univalent vector equation and its application to mixed second-order cone complementarity problems
Shunsuke Hayashi

It is known that the conic complementarity problems and the variational inequality problems are reformulated equivalently as vector equations by using the natural residual or Fischer-Burmeister function. Moreover, under some mild assumptions, those vector equations possess the weak univalence property. In this study, we first provide a sequential injective algorithm for a weakly univalent vector equation. We note that the algorithm can be cast as a prototype for many kinds of algorithm such as the smoothing Newton method, regularized smoothing Newton method, semi-smooth Newton method, etc. Then, we apply the prototype algorithm and the convergence analysis to the regularized smoothing Newton algorithm for mixed nonlinear second-order cone complementarity problems. We prove the global convergence property under the Cartesian P_0 assumption, which is strictly weaker than the monotonicity assumption.

4 - New stationarity concepts for mathematical programs with disjunctive constraints
Matus Benko, Helmut Gfrerer

Motivated by an increasing interest in mathematical programs with complementary constraints (MPCCs) and mathematical programs with vanishing constraints (MPVCs), in this talk we consider a generalization of these programs, the so-called mathematical programs with disjunctive constraints (MPDCs). We develop new stationarity concepts called Q- and Q_M-stationarity and discuss their properties. First, we define Q- and Q_M-stationarity for general mathematical programs, i.e. without the assumption of disjunctive structure, and compare them to the well known concepts of B- and S-stationarity. Next we apply them to MPDCs and as a result, we obtain an algorithm, based on Q-stationarity, for verification of M- or Q_M-stationarity of a point for MPDCs.

■ TB-16

Tuesday, 10:30-12:00 - 308A

DSS applications

Stream: Decision support systems
Invited session
Chair: Oluwafemi Oyemomi

1 - A preference modelling approach in tourism destination choice based on the FITradeoff method
Rodrigo José Pires Ferreira, Alexandre Leoneti, Adiel Teixeira de Almeida

Tourism destination choice can be influenced by several factors. Generally, decision makers are not confident about his/her preference structure in terms of tradeoff among these factors. This paper aims to structure the problem of choosing a tourism destination under the influence of factors such as hotel evaluation, travel time, the length of stay, cost of travel, shopping potential, and cultural attractions, natural landscapes and safety of the destination in terms of health conditions, violence and terrorism. In this context, the flexible, interactive elicitation tradeoff procedure for multicriteria additive models, FITradeoff is used. The flexibility and interactivity of FITradeoff can help the decision maker to choose what is the most attractive alternative providing minimum partial information about the criteria weights. It is observed that exploring less cognitive decision maker's effort and avoiding inconsistencies is a positive feature considering that the decision maker faces the natural difficulty to tradeoff among the criteria. The FITradeoff Software is available for download on request at www.fitradeoff.org/download

2 - Forecasting of bivalve landings with multiple regression and data mining: The case of the Portuguese artisanal dredge fleet
Manuela Maria de Oliveira, Ana Camanho, John Walden, Vera Miguéis, Nuno Ferreira, Miguel B. Gaspar

The bivalve dredge fishery is one of the most important artisanal fisheries in mainland Portugal involving a large number of fishers and vessels and the value of catches represents a large proportion of all revenue from traditional fisheries of coastal communities.The sustainability of this fishery has been at risk in the last few years, in part due to the occasional compulsory closures of the fishery activity as a result of phytotoxin episodes.In the absence of an accurate system to predict these phenomena, aggravated by their increased frequency, the goal of this analysis is to develop a decision support tool that can help administrative fishery authorities to forecast bivalve landings accounting for several contextual conditions.With data of 6 years relating to indicators of vessels characterization, fishing effort, weather conditions, phytotoxin episodes, stock-biomass indicators per species and tourism levels, it was explored the relationship between these factors and the monthly quantities landed using multiple linear regression models. The results showed that the impact of the contextual factors varies between regions, and also depends of the vessels target species. The accuracy of monthly bivalve landings forecasts was then improved using a Data Mining technique (Random Forests). This model has proved to be a robust decision support technique in this context, as the forecasts obtained showed accuracy levels ranging from 74% in the Southwest coast to 99% in the South.

3 - Assessing airline competition - A multi attribute decision making approach
Aman Gupta

Airline competition has been assessed for the most part using one attribute, with some exceptions where a combination of few attributes has been used. The research presents a multi attribute decision making approach to assess the competitiveness of airlines in the United States. Number of attributes and their related performance measures are considered. Different methods are applied to solve the multi attribute decision making model. Comparison of results from the methods used is presented.

4 - A comparative study on breast cancer risk factors assessment
Tuncay Gürbüz, Elif Doğu, Y. Esra Albayrak

Medical decision making is a complicated system that consists of many subsystems and elements with causal relationships. Numerous factors which are corresponding, opposing or competing must be considered during the process. These factors are affecting each other and the final decision of the decision makers; the physicists. Many mathematical models had been proposed as medical decision support systems using statistical models, linear programming, etc. In this paper, a comparative study on breast cancer risk factors assessment is provided between two different extensions of cognitive mapping method: Neutrosophic Cognitive Map (NCM) and Fuzzy Cognitive Map (FCM). FCM can successfully represent knowledge and human experience, introducing concepts to represent the essential elements and the cause and effect relationships among the concepts to model the behavior of any system and it has already been used to evaluate the weights of risk factors contributing the existence of breast cancer. Neutrosophic logic is an alternative to the existing logics and it represents a mathematical model of uncertainty, vagueness, ambiguity, incompleteness, inconsistency, redundancy, contradiction. NCM is Neutrosophic analogue of FCM which takes into account the indeterminate relations between the factors and represents the hesitancies of the decision maker in the model. The results of the study will provide a better understanding on which method would be more suitable for medical decision making.

■ TB-17

Tuesday, 10:30-12:00 - 309A

DEA and performance measurement 3

Stream: DEA applications
Invited session
Chair: Carlos Ernani Fries

1 - Second order cone programming approach to two-stage network data envelopment analysis
Kun Chen, Joe Zhu

Efficiency aggregation and efficiency decomposition are two techniques used in modeling decision making units (DMUs) with two-stage network structures under network data envelopment analysis (DEA). Multiplicative efficiency decomposition (MED) is limited to a very specialized two-stage structure under constant returns to scale (CRS) assumption. MED-based network DEA retains the property of the conventional DEA in the sense that input- and output-oriented models yield the same efficiency scores. However, if there are external inputs to the second stage, and/or some outputs leave the first stage and do not become inputs to the second stage, or if we assume variable returns to scale (VRS), MED has limited capability to address these extensions. Alternatively, multiplicative efficiency aggregation (MEA), although which is highly nonlinear and is impossible to be transformed into linear programming problems, considers extensions of two-stage network structure more appropriately. The current study discovers that MEA DEA model for general two-stage networks corresponds to a cone structure in disguise, and can be transformed into the form of second order cone programming (SOCP). Therefore, MEA in two-stage network DEA can be effectively and efficiently solved, regardless of the network structures. We show that additive efficiency decomposition (AED) can also be solved using SOCP and input and output-oriented AED models may not yield the same efficiency scores under CRS.

2 - A multi-criteria ranked indicator algorithm for performance measurement
Walter Garrett

This paper builds upon methods suggested by Data Envelopment Analysis (DEA), Principle Components Analysis (PCA), Composite Indices, and Balanced Scorecard methods to construct multi-criteria indices of performance measurements. It addresses the political and computational difficulties with those and similar methods, and suggests that these inhibit the adoption of such methods in non-technical domains such as education and service industries. The paper then introduces a Multi-Criteria Ranked Indicator Algorithm (MCRIA) in both unweighted and weighted variants, and demonstrates its applicability to performance measurement. Using sample data from U.S. public school districts, the results of the MCRIM method are tested and compared to traditional methods.

3 - On the relationship between technical efficiency and logistics services: Brazilian market case
Carlos Ernani Fries, Murilo Wohlgemuth, Fernanda Christmann

Logistics Service Providers (LSP) develop activities demanded by a shipper, providing integrated management of multiple logistics services. In addition to the basic services of inventory control, warehousing and transportation management, specialized LSP offer services such as cross-docking, packaging, freight forwarding, import/export services, project cargo management, tax support, reverse logistics among others. This study aims to establish the relationship between bundles of logistics services and technical efficiency of LSP that have operated in the Brazilian market from 2007 to 2015. Statistically significative relationships were obtained with two-stage DEA and regressions models. Results show that packages of services in specialized logistics sectors tend to lead to the efficient frontier defined by LSP that operate in these sectors. Therefore, inefficient LSP should rethink which bundles of services should they offer to their clients in order to achieve a better performance.

4 - Tax efficiency of Brazilian local governments and its determinants: a semi-parametric approach via beta regression
Luiz Henrique dos Santos Fernandes, Maria da Conceição Sampaio de Sousa

The present study measures the efficiency of the tax collection of municipalities in the northeastern of Brazil, one of the poorest regions of the country, and evaluates its determinants through a two-stage semi-parametric approach. In the first stage, efficiency scores were obtained with the method of Multiple Data Envelopment Analysis (MDEA), by using data from 2015. MDEA is a variation of the Data Envelopment Analysis (DEA), whose result consists of a mean of the efficiency scores calculated for each DMU (Decision Making Unit), considering all the possibilities of choosing subsets of the variables used as inputs and outputs. This method eliminates the random choice of variables and increases the discriminatory power of the DEA. In the second stage, a variable dispersion beta regression model was used to estimate the influence of environmental variables on the tax efficiency of local governments. The main results showed that tax efficiency was directly related with the estimated population, degree of financial self-sufficiency, which reflects the Vertical Fiscal Imbalance (VFI), value added to GDP by the industrial sector and the management transparency index. On the other hand, contributed to reduce tax efficiency factors such as dependence on grants from others levels of government and a high Herfindahl concentration index applied to the municipal taxes.

■ TB-18

Tuesday, 10:30-12:00 - 2101

Data science and analytics 1

Stream: Data science and analytics (contributed)
Contributed session
Chair: *Sanjay Melkote*

1 - A study on forecasting car sales volume of small sample a combined with big data
Yue He, Dan Zhang, Aixin Wang

With the improvement of people's living standards,car sales continue to rise, but the small sample size of the new model has brought great difficulties to the sales forecasting.In order to obtain more information and improve the prediction effect of small samples of new models, the paper first determines the influencing factors of automobile sales volume by literature research;After Collecting the relevant index data,tests the data collected;And then builds the autoregressive model of sales volume and the prediction model of big data index;Finally, the optimal prediction model is obtained by comparing the prediction effect and the fitting effect.The empirical study shows that the selected data, such as Baidu index and micro-blog related indicators can pass the test, and the use of the common ARMA model combined with big data has a better prediction effect.The prediction results of smaller errors can provide auxiliary decision support for the automobile production enterprises to arrange the production capacity plan, and effectively reduce the production waste and the inventory cost.

2 - Efficient parcel delivery by deriving customers' key locations
Stiene Praet, David Martens

Mobile location data can be used to discover personally meaningful places, extract semantics and even predict future locations. The goal of this paper is to use GPS location data to define customers' frequent locations and their corresponding semantics (home or work) in order to support delivery service providers in the planning of their deliveries. We propose an approach that starts by defining stay points, where a user stays for more than 10 minutes. These stay points are clustered into stay regions, making use of a density-based clustering algorithm with a radius of 100 meters and a minimum cluster size of 1. Thereafter, clusters are ranked based on the amount of visits and the total time spent, to obtain the user's most frequent places. Home place prediction is based on the idea that a user is most likely found at home during the night, from 0h to 5h. The work place is where a user is most likely found during weekdays from 9h to 17h. Finally, we introduce a baseline method for future location prediction, based on the counts per location for every hour of the week. A test set is used to evaluate our approach against three criteria: accuracy, usefulness and timeliness. The results are promising and indicate that our approach can detect and label the most frequently visited places (home and work) by using mobile location data. Therefore, this study offers opportunities for delivery service providers to optimize planning of the delivery flow.

3 - Railway demand forecasting: A machine learning approach
Neda Etebarialamdari, Gilles Savard, Miguel Anjos

Demand forecasting estimates the quantity of a product or service that will be purchased in the future. For railway industries, this will be the estimation of the number of passengers aiming to travel by train with a specific itinerary. Railway uses the predicted demand information for computing the protection levels on different products to satisfy their demands and maximize the total revenues. In this study, we present detailed analyses of applications of various machine learning algorithms combined with preprocessing techniques and feature engineering to predict the future bookings in railway industries, which, could be extended to other transportation or hospitality industries too. Dealing with large-scaled data with considerate amount of outliers and abnormalities in industrial data, plus the effects of trends and seasonality, as well as the dependency of demands on various exterior issues such as weather, strikes and etc., are main challenges to make an accurate demand prediction. The potential demand is investigated in two different aggregation levels; a general level and a more detailed-oriented less-aggregated level. Considering the data, we used the historical booking data of Paris-Brussels market. Finally, stacked generalization method combined with proper preprocessing techniques outperformed other approaches at both levels. We successfully achieved 11% Mean Absolute Percentage Error for level-1 aggregation and 18% Weighted Absolute Percentage Error for level-2.

4 - Predicting power outages using neural networks
Sanjay Melkote, Francesco Bariani, Mark Freeman, Hannah Myer, Priya Raman, George Slavov

Predicting the number and locations of power outages caused by weather events is a critical problem faced by all electric utilities. Accurate outage predictions enable utilities to optimize repair crew placement, decrease outage restoration times, reduce repair costs, and increase customer satisfaction. We tackle this problem at a major North American electric utility. Combining more than five years of historical outage data with weather data, we experiment with over 100 different predictive models to capture the relationship between weather events and outages in each service region of the utility. Our multilayer perceptron (MLP) neural network models perform best, predicting outages associated with benchmarked storm events with an average error of 18%. Our models outperform all published outage prediction models, most of which use a traditional classification/regression-based approach. We expect our models, which are currently being put into production at the electric utility, to greatly aid its storm recovery planning and result in significant repair crew cost savings.

■ TB-19

Tuesday, 10:30-12:00 - 2102AB

Inventory management and capacitated lot-sizing

Stream: Lot-sizing and related topics
Invited session
Chair: *Ganesh Janakiraman*

Chair: *Stéphane Dauzere-Peres*

1 - (R, S) policy with correlated demands
Mengyuan Xiang, Roberto Rossi, Belen Martin-Barragan

This paper addresses the single-item single-stock location stochastic lot-sizing problem under (R, S) policy. We assume demands in different time periods are dependent, and modelled as an auto-regressive process. We present a mixed integer linear programming (MILP) model for computing optimal (R, S) policy parameters. This model is built upon the piece-wise linear approximation of the first order loss function. Our model can be extended to discuss different variants of the stochastic lot sizing problem which include penalty cost scheme, service level constraints (α, and β). It can also be operated under lost sale settings. Our computational experiments demonstrate the effectiveness and versatility of our model.

2 - A Dantzig-Wolfe formulation and a column generation approach for the multi-level capacitated lot-sizing problem with set-up carryover and emission constraint
Nusrat Chowdhury, Fazle Baki, Ahmed Azab

There has been recently a growing concern of global warming, which is mainly attributed to our growing carbon footprint generated from the increased industrial activities worldwide. There is emission due to production, and holding and set-up of the production process. In this work, we study a multi-level capacitated lot-sizing problem for multi-product, multi-machine, and multi-period batch production system considering set-up carryover and emission. A Mixed Integer Linear Programming (MILP) model is formulated to determine the optimum lot-size with the objective of minimizing the total production, set-up and holding cost as well as that of the different emission reduction activities. A Dantzig-Wolfe decomposition approach is being developed to solve the proposed MILP model as well as a column generation procedure to solve the problem to optimality.

3 - Optimal policies for a production system with commitment cost subject to service level and mean waiting time constraints
Taher Ahmadi

In this paper, we consider a production firm which faces a Poisson customer demand and uses a base-stock policy to replenish its inventories from an outside source with a fixed lead time. The firm can use a preorder strategy which allows the customers to place their orders before their actual need. The time from a customer's order until the date a product is actually needed is called the committed lead time. The firm pays a commitment cost to the customers which is increasing in the length of the committed lead time. We minimize the long-run average inventory holding and commitment costs subject to two different constraint settings; service level should be greater or equal to a minimum service level threshold and the mean customer waiting time should be less or equal to a waiting time threshold. For such a system under the both constraint settings, we prove the optimality of bang-bang and all-or-nothing policies for the committed lead time and the base-stock policy, respectively. Furthermore, we show that there exists a commitment-cost threshold which dictates the optimality of either a make-to-order or a make-to-stock strategy.

4 - The solution of multiproduct inventory problem using mixed integer nonlinear programming
Edmea Cássia Baptista, Álvaro Lourenção, Adriana Cherri, Edilaine Soler, Fernando de Souza

One of the important components of planning and production control is the inventory management. The inventory models are widely investigated and they are of big interest of researchers, for more than a century. A great variety of works about this theme was published in the last years. Of the models found in the literature, a lot of them were developed taking into account the concepts of replacement point and periodic review, and they were solved by linear and nonlinear optimization techniques. In this work, we propose an inventory model, which explores the cited concepts and considers multiple products and multiple resource constraints. This model is formulated as a mixed integer nonlinear optimization problem and for its solutions the Branch and Bound method with Interior Point method for solving the search tree problems, is used. Computational tests are performed with the model and with the solution method adopted. An comparison with the linearized model is realized and the obtained results show the efficiency of proposal model and adopted method. Acknowledgments to CNPq (Proc. n. 309588/2013-8) for the financial support.

■ TB-20

Tuesday, 10:30-12:00 - 2103

Optimization of gas networks 2

Stream: Optimization of gas networks
Invited session
Chair: *Lars Schewe*

1 - Deciding robust feasibility and infeasibility using a set containment approach: An application to stationary passive gas network operations
Denis Aßmann, Frauke Liers, Michael Stingl, Juan Vera

A passive stationary gas network problem under uncertainty is studied. It is assumed that not all physical parameters - like for example the pipes' roughness values - are precisely known. The goal is to decide whether a given load can be satisfied by the network for all possible realizations of the uncertain data. Since the network problem is a nonlinear, non-convex polynomial system, the typical robust optimization techniques cannot be applied easily. Instead, a projection-based approach for deciding robustness of the system is proposed. This results in two polynomial optimization tasks, one to decide feasibility and one to decide for infeasibility, which are solved approximately using the Lasserre SDP hierarchy. A set of small instances is used to demonstrate practical feasibility of the approach.

2 - On probabilistic capacity maximization in stationary gas networks
Holger Heitsch

We consider a passive stationary gas network, where exits can nominate their loads only according to given booked capacities. The network owner has to make sure that all nominations complying with the booked capacities can be satisfied by a feasible flow through the network satisfying given lower and upper pressure bounds at its nodes. Since several nomination patterns may turn out to be highly unlikely, he may content himself with guaranteeing this feasibility only with a certain high probability level, being aware that rare infeasibilities in the stationary model can be compensated for by appropriate measures in the dispatch mode such as exploiting interruptible contracts. This probabilistic relaxation of an originally worst-case-type requirement for feasibility, gives the network owner the chance of offering significantly larger booked capacities. For a given setting the probability of nominations being technically feasible can be larger than the probability desired by the network owner. This degree of freedom can be used in order to extend the currently booked capacities by a value which still allows a reliable network operation. The resulting optimization problem is a joint model of robust and probabilistic constraints. We establish an approach based on spheric-radial decomposition of Gaussian type random variables to deal with such models algorithmically. For simplicity, our numerical study focuses on stationary gas networks exhibiting tree structure.

3 - Discrete versus continuous gas network expansion planning
Ralf Lenz, Robert Schwarz

Gas transportation companies often need to extend their networks, in order to enable feasible operations. A common strategy to enhance the network capacity in practice is using loops. The concept of looping is to build new pipelines in parallel to existing ones. Two different approaches to modeling this problem exist in the literature, that is using continuous loop lengths (also known as splitpipe problem) or discrete loop lengths. In this talk, we compare the continuous and discrete loop expansion planning problems. We analyze problem properties, such as the structure and convexity of the underlying feasible regions and show that the Braess' paradox also occurs in the context of loop expansions. Moreover, we state assumptions under which a solution of the splitpipe problem can be transformed to a solution of the discrete problem. The talk concludes with a computational study comparing the continuous and the discrete formulations.

4 - Modeling inefficiencies in booking based gas markets
Jonas Egerer, Julia Grübel, Veronika Grimm, Lars Schewe, Martin Schmidt, Gregor Zöttl, Alexander Martin

The gas market design in Europe follows the idea of entry-exit zones with a virtual trading hub. It allows for unbundling of the pipeline operation (by the transmission system operator, TSO) from gas trading. The gas network users buy the rights (bookings) to inject or to discharge from the respective market zone and to access its trading hub. TSOs have to guarantee the operation of the gas network for all nominations consistent with the realized bookings. They restrict bookable capacities to ensure technically feasible pipeline operation. We apply a single-level booking-based welfare maximization problem for entry-exit systems, which is obtained from a bilevel booking-based profit maximization problem under the assumptions of regulated TSOs and perfect competition. For the case of multiple entry-exits zones, the model determines welfare optimal nominations in the market equilibrium, given restrictions on bookable inter-zonal entry and exit capacities, which are determined ex-ante in a technical network model. In a second step, we assess the inefficiencies induced by the entry-exit scheme by comparing the result with the solution of a welfare maximization problem that accounts for technical constraints of individual pipeline capacities. For the application, we use a stylized passive gas transport network of Germany, which represents important infrastructure (pipelines, gas storage, and gas power plants), im- and exports, and the division of Germany in two entry-exit zones.

■ TB-21

Tuesday, 10:30-12:00 - 2104A

Simulation and modeling without optimization

Stream: Simulation
Invited session
Chair: *Andrew Collins*
Chair: *Patrick Hester*

1 - Assessment games
Sue Collins

Assessment Games are used in NATO to evaluate future concepts. One of the most popular games is the Concept Assessment Development Game (CDAG), a qualitative analytical method employed to test and develop documents. It is a table-top game that focuses on challenge and discussion, combining the intellectual freedom of brainstorming with the structured approach and control of a simulation and the challenge of red teaming. The CDAG can be used at various stages of a concept document's development but is best employed as a theoretical low-risk test of a concept. It brings together diverse sets of stakeholders, including the policy makers, end users, and external organizations affected by NATO. Participants role-play in teams and the context is set through theoretical scenarios. Capabilities are simulated through cards. The idea of the CDAG is to "play the concept" in order to discover gaps and improvements. The CDAG goes well beyond a "document review" and can provide significantly more valuable results than a regular review workshop. Assessment games been successfully employed for several areas in NATO, including Logistics, Maritime Situational Awareness, Countering Autonomous Systems and Urbanization. In this presentation, an overview of the CDAG will be given including discussion on its strengths and weakness. A simple case-study will be shown to demonstrate the technique and discussion will be given on its future applicability.

2 - On the lack of penetration of soft OR in United States of America
Patrick Hester, Andrew Collins, Ying Thaviphoke

The use of soft Operations Research (OR) methods is widespread throughout Europe due to their ability to assist problem analysts in understanding the qualitative aspects of their complex problems. Conversely, in the United States, these methods are only beginning to catch on among the OR community. In particular, the simulation community's current focus is on simulation-optimization, aka the obsession that a model must produce the correct answer. Simulations have many purposes including theory-building, game storming, etc. but these have been sidelined by the OR community. Why is that? We contend that it is due in part to a lack of empirical evidence of the utility of their use. In this presentation, we discuss the lack of penetration of soft OR techniques in the United States of America and the need for their use as a complementary perspective to analytically-charged, optimization-driven simulation approaches so common among Western practitioners and academics. We conclude with some recommendations for a path forward to increase the use of these techniques in the USA. We make the case for empirical investigation of the use of soft OR to address complex problems and we provide guidelines for what such an investigation might entail.

3 - Simulation-based assessment of unmanned aerial vehicles traffic congestion in metropolitan area
Seyun Kim, Jungwoo Cho, Yoonjin Yoon

The public and commercial demand of Unmanned Aerial Vehicles (UAV) is growing exponentially in near future. Though there are enormous potential of UAV usage in urban areas from parcel delivery to emergency response, they pose inevitable risk to city population and infrastructures. This study examines how large UAV demand will affect the urban airspace when there is no infrastructure system or traffic rules in place for UAVs. We identify congestion locations by dividing the airspace into the three dimensional grids. Highly urbanized area of Gangnam in Seoul metropolitan city is chosen for the study area. For the result, we observe a few persistent and temporary congestion bottlenecks at specific areas, which implies the need of operational procedures and flow planning strategies to manage this new air traffic in a safe and efficient manner.

■ TB-22

Tuesday, 10:30-12:00 - 2104B

Simulation, stochastic programming and modeling

Stream: Simulation, stochastic programming and modeling (contributed)
Contributed session
Chair: *Benjamin Legros*
Chair: *Dinesh Sharma*

1 - Mathematical analysis of machine repair problems with common cause failure, hot spares and multiple repairmen
Dinesh Sharma

We study the machine repairable system comprising M operating machines, H spares and more than one repairman where "the partial server vacation" is applied on some of the repairmen. In this system, the first repairman never takes vacation and always available for servicing of failed machines while other repairmen goes to random length vacation whenever the number of failed machines are less than N, N +1 respectively. Machines may breakdown individually or due to common cause according to Poisson process. Vacation time and service time of repairmen follows the exponential distribution. Recursive approach is used to obtain the steady state probabilities. A cost model is developed to determine the optimum value of failed machine maintaining the system availability and other performance measures. Sensitivity analysis is investigated for optimal conditions and also analyzes the reliability characteristics of the system.

2 - Unintended consequences of optimizing a queue discipline for a service level defined by a percentile of the waiting time
Benjamin Legros

In service systems, the service level is often represented by a percentile of the waiting time. This may create an incentive for managers to modify the traditional first-come-first-served discipline of service. For this purpose, we consider the analysis of the M/M/s queue under the queueing discipline which minimizes a given percentile of the waiting time. We prove that a strict non-preemptive priority should be given to the oldest customer who has waited less than the acceptable waiting time. We derive closed-form expressions of the performance measures under this discipline, and evaluate the unintended consequences that this discipline may have on service levels and on staffing decisions. In particular, we show that although this discipline may reduce staffing costs, it leads to excessive wait for non-prioritized customers.

3 - Morphing M/M/m: A new view of an old queue
Neil Gunther

2017 is the centenary of A.K. Erlang's paper on waiting times in an M/D/m queue. M/M/m queues are used to model call centers, multicores & the Internet. Unfortunately, those who should be using M/M/m models often don't know applied probability theory. Our remedy defines a morphing approximation to M/M/m that's accurate within 10% for typical applications+. The morphing residence-time formula is both simpler and more intuitive than the exact solution involving the Erlang-C function. We have also developed an animation of this morphing process. An outstanding challenge, however, has been to elucidate the nature of the corrections that transform the approximate morphing solution to the exact Erlang solution. In this presentation, we show: 1) the morphing solutions correspond to the m-roots of unity in the complex z-plane; 2) the exact solutions can be expressed as a rational function with poles; 3) these poles lie inside the unit disk and converge around the Szego curve with increasing m-servers; 4) the correction factor for the morphing model is defined by the deflated polynomial; 5) the pattern of poles in the z-plane provides a convenient visualization of how the morphing solutions differ from the exact solutions.

4 - Single-period newsvendor problem under random end-of-season demand
Subrata Mitra

Newsvendor problems, which have attracted the attention of researchers since 1950's, have wide applications in various industries. There have been many extensions to the standard single-period newsvendor problem. In this paper, we consider the single-period, single-item and single-stage newsvendor problem under random end-of-season demand, and develop a model to determine the optimal order quantity and expected profit. We prove that the optimal order quantity and expected profit thus obtained are lower than their respective values obtained from the standard newsvendor formulation. We also provide numerical examples and perform sensitivity analyses to compute the extent of deviations of the 'true' optimal solutions from the newsvendor solutions. We observe that the deviations are most sensitive to the ratio of the means of the demand distributions. The deviations are also found sensitive to the contribution margin, salvage price, coefficients of variation of the demand distributions and correlation between seasonal and end-of-season demands. We provide broad guidelines for managers as to when the model developed in this paper should be used and when the standard newsvendor formulation would suffice to determine the order quantity. Finally, we present the concluding remarks and directions for future research.

■ TB-23

Tuesday, 10:30-12:00 - 2105

MADM principles 2

Stream: Multiple criteria decision analysis
Invited session
Chair: Jung-Ho Lu

1 - A hybrid multiple attributes decision-making model for evaluating wetland restoration and environmental protection plan
Chie-bein Chen, Vivien Y.C. Chen, Gwo-Hshiung Tzeng, Tze Jen Wang

Wetland restoration and environmental protection plans are very important types/issues of plans that relate to human welfare and safety. Wetland restoration and environmental protection plans are affected by many interrelationship aspects/attributes. Therefore, the purpose of this study is to probe how to use quantitative and qualitative measurements of restoration and environmental protection plan to create plan indices in aspects/attributes, as well as how to help these indices towards achieving the aspiration level for each aspect/attribute. Previous efforts to measure wetland restoration and environmental protection plans have assumed that the attributes are independent, but this assumption does not hold in real-world applications. Therefore, in this study, a DEMATEL technique is used to construct the INRM, and along with a basic concept of ANP to construct DANP (DEMATEL-based ANP) and to determine the influential weights of environmental wetland attributes and overall performance score. Finally, an empirical case study is applied to illustrate the DANP method is feasibly used to measure and evaluate for improving wetland restoration and environmental protection problems in decision-making and achieving the goal of wetland environmental sustainable development for living comfortable and safe environment.

2 - Board characteristics and firm performance: Evidence from Taiwan
Jung-Ho Lu, Fan-Wen Huang

In the past decades, corporate governance has become a popular area of discussion in the United States and, recently, also in Taiwan. Improper corporate governance system has been determined as one of the main reason suffering the serious consequences on the Asian financial crises happened since 1997. The board of directors is considered to be an important corporate governance mechanism. Thus, the purpose of this paper is to investigate the relationship between board characteristics and firm performance. This study focuses on TWSE listed companies and limits the sample to the electronics industry which totals 396 companies at the end of year 2014. Then, it uses a linear regression framework and sets up the regression of the performance model to examine if board characteristics impact firm performance. The results indicate that the proportion of independent directors and the remuneration of board members have a positive impact on firm performance whereas board size has negative impact.

3 - Using DANP to establish a model for finding a best mentor: A study of Taiwan chefs
Chin-Tsai Lin, Jung-Ho Lu, Ting-Ting Chang

A review of mentoring relationships studies emphasized the career, psychosocial, and role model functions of the relationships, wherein a good mentor plays an important role in career success. Therefore, the purpose of this article is to focus on understanding the criteria of an ideal mentor and create a mentor-protégé selection model. To finding a best mentor is a complex decision-making process that combines numerous conditions, that general decision models cannot take the dependence and interrelationships among different levels of criteria into consideration, therefore, this study was investigated through qualitative and quantitative analyses of in-depth interview and a MCDM model, combining the DEMATEL and DEMATEL-based Analytic Network Process (DANP). The technique has been widely employed, but has not been used in the selection a mentor, participants of qualitative approach were 36 senior chefs, further quantitative approach completed by 20 chefs. This study found that 4 core criteria and 14 sub-criteria, core criteria including career support, affection support, role model and family support, and an influential network relations map was obtained. The results of this study provided the criteria and a choose model for chefs to select the mentor they want to follow, it is a contribution to the practical mentor election of the workplace and further promote the development of career.

■ TB-24

Tuesday, 10:30-12:00 - 301A

Hospital planning 1

Stream: CORS SIG on healthcare
Invited session
Chair: *Peter Vanberkel*
Chair: *Michael Beeler*

1 - Fighting fake medicine in global supply chains
Michael Beeler, David Simchi-Levi, Cynthia Barnhart

Counterfeit medicines and medical supplies are a massive global problem, with deaths from fake tuberculosis and malaria drugs exceeding 700,000 per year according to the WHO. In recent years, several leading global drug brands and medical product companies have adopted effective SMS-based product verification systems to protect themselves and their consumers against counterfeiters. The adoption of such technology, however, has been far from universal. We use a game-theoretic model of competitive generic drug markets to that helps explain this low uptake, and identifies the circumstances in which mandating the use of product verification systems greatly reduces counterfeiting and improves total manufacturer profit over the best-case laissez-faire Nash equilibrium. Our model also sheds light on the market conditions (i.e., potential excess profits on counterfeits, prior consumer awareness of and sensitivity to counterfeiting, law enforcement penalties) that are more or less likely to lead to higher rates of willful counterfeit procurement, higher rates of anti-counterfeiting activity by industry, and the greatest benefit from financially incentivizing consumers to use product authentication technologies.

2 - Bed Mapping with surge protocols: Implementation of generalized DES model at three hospital
Carolyn Busby, Michael Carter

A DES model has been created to simulate the flow of patients through the Emergency Department, Operating Rooms and inpatient beds. The generalizable model is designed such that the model can be successfully applied to a wide variety of hospitals. Surge policies are included to more accurately capture the patient flow as the hospital occupancy levels change. The model design, the importance of the inclusion of surge protocols, and the implementation of the model at three very different hospitals will be discussed.

3 - MSICU Length-of-stay prediction model based on NEMS
Felipe Rodrigues, Greg Zaric, John Wilson

Length-of-stay (LOS) is a critical metric for Intensive Care Unit (ICU) resource planning. If a hospital can estimate its ICU patient's LOS, then it can better schedule staff, elective surgeries and allocate beds to downstream wards. We estimate several LOS prediction models containing a nursing workload scoring metric called "Nine Equivalents of Nursing Manpower Use Score" (NEMS). Using data from a large Canadian University Hospital, we observe that LOS can be non-monotonic in NEMS. Therefore, we fitted models that account for patient heterogeneity. We show that our models are able to provide predictions that can be used in real time in ICU short term resource planning.

4 - Alternative care providers in rheumatoid arthritis patient care: A queueing and simulation analysis
Toni Tagimacruz

Rheumatoid Arthritis (RA) is a chronic autoimmune disease that has cumulative humanitarian and economic burden on the patient and society. Patients diagnosed with RA requires lifelong monitoring by a rheumatologist or rheumatology team. For patients just diagnosed with the disease, it is crucial that a disease modifying anti-rheumatic drug (DMARD) therapy be initiated within 12 weeks of the onset of symptoms to prevent joint damage. The goals of meeting early intervention targets and managing quality of life are essential in RA patient care but are at odds when competing for limited rheumatologist's capacity. One strategy used to address issues related to specialist's capacity is the inclusion of an alternate care providers (ACP) at certain portions of RA patient care. Using queueing theory, we develop two closed, multi-class queuing networks with class switching. Mean value analysis is used to solve for the performance measures to compare the models and analyze the model under different parameter conditions. Using simulation, we relax certain assumptions and analyze the effect on system performance. We use aggregated data from an actual rheumatology clinic to inform the choice of model parameters for the illustrative case.The results provide valuable insights for decisions pertaining to resource requirements, capacity allocations and feasible patient panel size as they impact timeliness of care and resource utilization.

■ TB-25

Tuesday, 10:30-12:00 - 301B

OR for development and developing countries 2

Stream: OR for development and developing countries
Panel session
Chair: *Subhash Datta*
Chair: *Leroy White*
Chair: *Sue Merchant*
Chair: *Gerhard-Wilhelm Weber*

1 - Optimizing market strategies for peanut farmer coops
Trilochan Sastry

Small farmers are unable to effectively access markets with their raw produce. They cannot process it or market it in distant urban markets. Local markets often do not provide them with remunerative returns. Farmer Coops help in overcoming this problem by pooling and aggregating produce from several farmers, processing it to get a higher value in the market. However farmer coops face a problem. Both the supply is uncertain, as well as the market price. Prices also fluctuate. In the absence of transparent market information, coops also face problems while negotiating prices with big buyers. We model this problem and suggest ways of tackling this problem. We use data from a peanut coop, but the basic insights apply to other processed commodities with supply and price uncertainty.

2 - An adaptive large neighbourhood search heuristic for the bid construction problem in total truckload transportation procurement auctions
Hammami Farouk, Monia Rekik, Leandro Coelho

In combinatorial auctions for the procurement of transportation services, bid construction problems (BCP) are studied since the 1990's but the problem is still open due to its NP-hard nature. Large shipping companies are capable of reducing their transportation costs by using combinatorial auctions mechanisms in which carriers competitively bid on individual or groups of lanes (origin-destination pairs). Our work addresses the BCP via combinatorial auctions in truckload procurement with a heterogeneous fleet and maximum tour length constraints. During the auction, each carrier has to solve a BCP in order to choose the set of lanes that are the most profitable to bid on. We formulate a mixed integer linear programming (MILP) model for the BCP to identify the profitable lanes based on the routes that vehicles will travel in order to maximize profit. To solve the problem, an adaptive large neighborhood search (ALNS) heuristic is developed. We propose eight removal and three insertion operators and a local search procedure to improve solutions and a greedy procedure used to construct the initial solution. The mathematical model and the ALNS heuristic are tested then compared on realistic instances with up to 350 nodes. Computational results show that the ALNS heuristic performs well in terms of CPU time and solution quality.

3 - Implementation and evaluation of the targetting performance of the 4Ps program in Northwestern Philippines

Milagros Baldemor

Poverty alleviation has always been the primary target of the development efforts of the Philippine government as articulated in all its strategic plans and policies. To help eradicate the problem, a social assistance program, the Pantawid Pamilyang Pilipino Program (4Ps) was formed in 2008 with the main purpose of helping the poorest of the poor by providing them with cash subsidy provided that they comply with certain conditions on schooling and health of their children. This paper presents the results of a study that identified the level of implementation of the program as to (a) policies; (b) personnel involved; (c) monitoring and evaluation; and (d) systems of operations in terms of: (1) Beneficiary Update System (BUS); (2) Compliance Verification System (CVS); (3) Grievance and Redress System (GRS); and (4) Supply Side Assessment (SSA); (e) service providers; and (f) stakeholders and also the level of attainment of Millennium Development Goals (MDGs) as to (a) well-being; (b) poverty index; (c) education; and (d) gender equality. Using the 2014 Annual Poverty Indicators Survey (APIS), this paper presents the results that the program was highly implemented but it is not as effective as expected because it was only able to cover 33.12% of poor and has about 28.4% leakage rate in its implementation in the Northwestern Philippines. However, based on Coady-Grosh-Hoddinott indicator, the program is still progressive.

4 - The Kerkenes eco-center project in Central Anatolia, Turkey

Gerhard-Wilhelm Weber, Francoise Summers

In 1993, the Kerkenes Project was inaugurated to study the Iron Age capital that had once stood on the Kerkenes Dag which overshadows the village of Sahmuratli. From the outset, the Project Directors were conscious that this international research project would not only have an impact on the village and the local area, but also that it had potential for development at regional and inter-regional level. A central concern was, and continues to be, that any impact, social, cultural or economic, should be for the benefit of the village and the region. In this talk, we survey on different facets of this project, and discuss on the potential of OR to improve living conditions in the rural countryside. Acknowledgement: This presentation bases on the hard-work and devotion of professors Francoise and Geoffrey Summers, Soofia T. Elias-Özkan, their team and the citizens of Kerkenes.

■ TB-26

Tuesday, 10:30-12:00 - 302A

Power sector perspectives and equilibrium modeling

Stream: Equilibrium problems in energy
Invited session
Chair: *Christian Skar*
Chair: *Martin Kristiansen*

1 - A linear complementarity model for assessment of storage technologies in mixed energy and capacity markets

Magnus Askeland

A linear complementarity model of a power market is developed. The model comprises several market participants such as thermal power producers, storage units, system operator, demand side, and renewable generation. The model determines market clearing, optimal investments and operation for all market participants. The energy market is present in all analyses and, in addition to covering variable costs, contribute significantly to capacity remuneration. In addition, the implementation of a capacity market provide a new source of remuneration for thermal units and possibly energy storage. An important focus is the mechanisms with both of these markets in the same system to facilitate energy balance and capacity adequacy. From this, the properties of a capacity market are explored and potential adequacy issues regarding the inclusion of energy storage in such markets discovered. Further, a cap and trade market for carbon emissions is implemented alongside the energy only market. Power producers pay a tax according to how much they emit due to the production of energy. Given a fixed tax, the amount of emissions vary significantly depending on the presence of energy storage. Further, an emission quota can be applied and the model gives the resulting emission tax, installed capacities and operation. Consequently, it is less costly to achieve a given emission target when including energy storage compared to cases with limited or zero energy storage.

2 - Coordinated microgrid energy management with a multi agent approach

Sambeet Mishra, Chiara Bordin, Asgeir Tomasgard, Ivo Palu

Optimizing the self-contained MG without sharing or retrieving information regarding the surrounded energy infrastructure drastically influences the decisions. In the proposed work, an agent is articulated as the decision-making entity present in each MG. It also shares limited information with agents from neighboring grids. Agent objectives are optimising the energy management, accommodating capacity expansion, considering potential connections among MGs, scheduling of energy units (i.e. conventional generators, renewable and batteries). This work presents a novelty approach for the optimization of MGs in an agent based smart communication framework: the key contribution is coordinated decision making as opposed to the traditional self-contained system optimisation. In the coordinated decision making process each individual makes an informed decision while keeping the neighboring system in purview and evaluating possible connections. The main motivations for evaluating MG connections are: forecast increment of demand that may be optimal to be fulfilled by neighbour MG instead of by the single MG itself; better utilization of energy by an optimised combined scheduling of conventional generators that belong to different MGs; possibility for a MG to exploit the exceeding energy produced by a neighbour MG, or to share investments. The proposed agent co-ordination for decision-making is inspired by the Brooks-Iyengar algorithm for distributed decision making.

3 - Congestion management in a stochastic dispatch model for electricity markets

Mette Bjørndal, Endre Bjorndal, Kjetil Midthun, Golbon Zakeri

We discuss the design of electricity markets with stochastic dispatch. Our discussion is based on a model framework similar to that in

(Pritchard et al. 2010) and (Morales et al. 2014), where an electricity market with two sequential market clearings is used. The stochastic market clearing is compared to the (standard) myopic market model in a small example, where wind power generation is uncertain. We examine how changes in market design influence the efficiency of the stochastic dispatch. In particular, we relax the network flow constraints when clearing the day ahead market. We also relax the balancing constraints when clearing the day ahead market to see if this additional flexibility can be valuable to the system.

4 - Benefit allocations of multinational grid investments using cooperative game theory
Martin Kristiansen

There are multiple countries involved in, or affected by, multinational grid investments needed to cope with energy- and climate targets in Europe. National incentives to participates in such projects does therefore play an important role since there is no authority that decides on behalf of those countries, in contrast to the Federal Energy Regulatory Commission (FERC) in the US. We present a large-scale case study of the North Sea Offshore Grid (NSOG) applying Shapley Value from cooperative game theory in order to bridge the gap between conventional allocation methods and allocation methods that considers a country's strategic position as well as the sequence of project deployment. A multi-objective approach is pursued with respect to monetary values and metrics concerning energy- and climate policies, such as the share of renewables and CO2 emissions. Net-benefits are calculated with a bi-level, two-stage stochastic program over multiple time steps, where the generators are able to respond with capacity expansion after a system planner decides upon transmission investments. The presented methodology gives valuable insight what concerns benefits for the greater good in multinational projects, with a fair reallocation of the initial benefits that arise from a direct market impact using side-payments.

■ TB-27

Tuesday, 10:30-12:00 - 302B

Behavioural issues in environmental-decision making 1

Stream: Behavioural OR
Invited session
Chair: Alice H. Aubert

1 - Analysing the behavioural factors in green supplier selection
Mehrnoosh Enjelasi, Behnam Fahimnia, Andrew Collins

Green supplier selection has not been broadly explored in the literature from a behavioural viewpoint. This study analyses behavioural factors that can influence green supplier selection in the Fast Moving Consumer Goods (FMCG) industry. A discrete choice experiment is designed to investigate the impacts of behavioural factors on green supplier selection decision making. It studies the extent to which the preferences of supplier managers can influence green supplier selection decisions. It also investigates the role of environmental sustainability policy in the decisions made by supplier managers. Last, we examine the correlations between the preferences of supplier managers, their propensity to put their preferences into practice, and their propensity to be influenced by the environmental sustainability goals of the company.

2 - Using trade-off preferences to identify non-additive multi-criteria value functions
Fridolin Haag, Peter Reichert, Nele Schuwirth, Judit Lienert

To evaluate alternatives across criteria, commonly a multi-attribute value function is used which combines the results of value functions of lower-level objectives by an additive aggregation scheme. If decision makers prefer a fair fulfillment of all sub-objectives to a poor fulfillment of one compensated by a good fulfillment of others, this cannot be represented by the additive model. Other aggregation schemes are required, for which a feasible approach to elicitation has been lacking. We propose a novel approach for estimating parameters of multi-attribute value functions of arbitrary functional shapes. We assume a random elicitation error and estimate the parameters by maximum likelihood estimation based on trade-off statements of the decision makers. This probabilistic method allows a proper representation of the preferences and their uncertainty. Instead of asking only one trade-off between two criteria, we ask for multiple trade-offs at different points in the value space to be sensitive to non-additive aggregation. An interactive elicitation tool has been developed to aid this task, which is considered cognitively demanding. The approach is concretized for hierarchically constructed value functions. The resulting model is able to represent a wide range of preference structures. We illustrate this transparent and consistent elicitation and modeling approach by quantifying preference models of experts for an assessment of the ecological state of rivers.

3 - Environmental decision analysts, let's be playful!
Alice H. Aubert, Judit Lienert

"Being playful is the engine of innovation and creativity" claims Eric Zimmerman, game designer and researcher, in his manifesto for a ludic century. This manifesto opens the book A playful world, gathering research on the rationales, motivations and still-open questions linked to the use of game elements in our daily life to facilitate various tasks. The introduction of game elements in other tasks is called gamification. In Operation Research, serious games and gamification are occasionally used, e.g. to promote citizens participation in shared resource management planning, or to teach (the most famous OR serious game is the beer game, created in the 1960s and still used today). In the talk, I will present the results of a review of 43 serious games on water issues. After summarizing the characteristics of serious games and gamification, I will discuss the benefits and drawbacks of their use in environmental decision analysis. Many behavioral consequences are expected, some positive and others challenging. Serious games and/ or gamification examples exist for most Multi-Criteria Decision Analysis steps. Whether or not adopting them on a regular basis for environmental decision support needs to be discussed. Moreover, behavioral studies to test the challenging drawbacks are a prerequisite, as highlighted in the review.

4 - Adaptive governance with open traceable accountable cognizant science and policy
Pierre Glynn, Alexey Voinov, Carl Shapiro, Karen Jenni

Science and policy governance, and environmental decision making, suffer from a number of common problems, including insufficient Accessibility, Traceability, and Accountability (ATA) in the processes governing both science and policy. The lack of recognition of how Biases, Beliefs, Heuristics, and Values (BBHV) shape the construction of both science and policy is another problem. Understanding the role of BBHV in decision-making is critical to (1) understanding individual judgments and choices, (2) recognizing potential differences between societal "wants" and societal "needs", and (3) identifying "winners" and "losers" of policy decisions and actions. Societal acceptance for proposed solutions, policies, or actions can be fostered by enhancing participatory processes and by providing greater ATA, or what we call "Babel Fish" enabled responsive communication (cf. Hitchhiker's Guide to the Galaxy). Beyond science, this is needed for shared understanding of the laws, rules, and traditions that constrain decision-making. An adaptive science-infused governance framework is proposed that seeks greater cognizance of the role of BBHV in shaping science and policy choices and decisions, and that also seeks to add Open Traceable Accountable Policy-making to "Open-Science" processes. We discuss tools and approaches that could help implement our adaptive-governance framework, as well as situations and issues that it would be best suited to address.

■ TB-28

Tuesday, 10:30-12:00 - 303A

Kidney exchange programs

Stream: OR in healthcare
Invited session
Chair: *Kseniia Klimentova*
Chair: *Joao Pedro Pedroso*

1 - Study of a heuristic for efficient computation of optimized sets of chains and cycles observing the Spanish KEP policies
Francesc Castro, Esteve del Acebo, Miquel Bofill, Mateu Villaret

The Spanish KEP selection procedure is based on a greedy algorithm that aims at maximizing the number of transplants taking into account the reparability of last-minute failures. Such a procedure deals separately with cycles and altruistic-donor-based chains. We have carried on a simulation which compares the Spanish procedure with an Integer Programming (IP) approach intended at just maximizing the number of proposed transplants. Results obtained show that while the number of implemented transplants is slightly higher with the IP approach, the current procedure is superior in other points, such as providing a lower number of times patients suffer a non-made proposed transplant. Based on the results of our simulation, we propose a procedure that embraces the strong points of both approaches observing the Spanish KEP policies. Our proposal (i) will take into account not only the number of scheduled transplants but also the robustness (ease of repair) of the proposed solutions, and (ii) will try to simultaneously consider the computation of both transplant cycles and altruistic-donor-based chains, for which we design a heuristic algorithm intended at maximizing the expected length of the chains. A repair mechanism to proceed when last-minute failures occur will be incorporated too. Although our purpose is focused on the Spanish case, it could be easily arranged to a wider context such as the one fostered by the EU in the sense of unifying KEPs of different countries.

2 - Kidney exchange programs: A game
Margarida Carvalho, Andrea Lodi, Ana Viana, Joao Pedro Pedroso

Recently, many countries legislation have extended the transplantation alternatives for renal patients. Besides kidney transplantations from a deceased donor or from a compatible living donor that is a patient's relative or friend, kidney exchange programs have been set. These programs allow exchanges between a patient in an incompatible pair and a compatible donor in another incompatible pair. The larger a pool of incompatible patient-donor pairs, the more kidney exchanges can be achieve. Thus, exchange programs between different entities (hospitals or countries) have potential to increase the social benefit. Kidney exchange programs with two entities and restricted to pairwise transplantations, modeled as a non-cooperative game, have shown to have good outcomes, Nash equilibria, in terms of social welfare. We study the generalization of this game and compare it with individually rational and strategyproof mechanisms.

3 - Fairness in multi-agent kidney exchange programs
Kseniia Klimentova, Nicolau Santos, Joao Pedro Pedroso, Ana Viana

Kidney Exchange Programs are established in a number of countries to provide an alternative patients with end stage renal disease, that have a a donor willing to donate a kidney to that patient but the pair is not physiologically compatible. In a multi-agent frame we should consider that several programs jointly collaborate, aiming to increase the total number of possible transplants. As an example, the possibility of creating international pool for a number of countries in Europe is now under discussion. There may be multiple optimal solutions for a given multi-agent pool, and some may benefit one agent more than others. Therefore it is necessary to define a procedure that conveniently select an optimal solution in a way that in the long-term all parties benefit equally. We use Integer Programming to model different policies that try to fairly balance the benefit of each agent in a long-term run of the program. The models are validated with exhaustive computational experiments.

■ TB-30

Tuesday, 10:30-12:00 - 304A

Forest value chain design 2

Stream: OR in forestry
Invited session
Chair: *Mikael Rönnqvist*

1 - General portrait and performance evaluation of wood yard design
Marta Trzcianowska, Daniel Beaudoin, Luc LeBel

Wood yards fulfill an important role in the forest supply chain by allowing to efficiently meet raw material demands of manufacturing processes. Wood yard activities are directly influenced by upstream and downstream operations within the supply chain. Wood yard performance is closely related to its design. The wood yard design problem has attracted little attention in the scientific community. Most existing documents deal with specific sub-problems with little consideration on their interactions. We propose that a methodology specific to wood yard design is required. The first step in developing a wood yard design methodology was to conduct an analysis of existing wood yards in Eastern Canada. Detailed information on throughput, equipment, personnel, operating rules, etc. were gathered by means of questionnaires, site visits and meetings with management staff. That database was used to benchmark wood yard performance by means of Data Envelopment Analysis (DEA). This analysis allowed us to identify the most sensitive factors that influence wood yard performance, and determine best practices in wood yard design. These results will be used in the next step of our project, which is to develop the wood yard design method. We present a description of current practices in wood yard design in Quebec. We also discuss their performance based on results of technical efficiency evaluation. Finally, we discuss the wood yard design practices most suited for sawmill in Eastern Canada.

2 - A generic framework for analazing the sustainable integration of new products: An application to the forest value chain
Louis-Alexandre Lapointe, Mustapha Ouhimmou, Mikael Rönnqvist

Behind the scene of successful sales, logistics networks are planned by organizations towards the end goal of making profits through well-defined product portfolios. Nevertheless, these structures, as complex as they can get, are built over raging water on a thin layer of ice. The question is neither if it will break nor when, but rather how to be proactive about those business life-threatening factors. In fact, the capacity of the companies to adapt to an increasingly complex world might be jeopardized by its lack of innovation. Nowadays, companies can acquire a competitive advantage by integrating the concept of sustainable development in their product portfolio and their logistics networks. The question to be developed is: how to maximize the value creation of an existing regional supply chain network by introducing new products and by considering sustainable development? In the context of a regional economy, the strategic allocation of natural resources and their products between stakeholders could generate better economic benefits for all actors by optimizing the value chain. A generic mathematical framework is developed to design a regional value chain network where the impact of integrating new products can be evaluated. The model is applied to a case study in the Mauricie region (Québec, Canada), where the introduction of new products is evaluated for the forest value chain.

3 - Techno-economic analysis and capacity planning model for a kraft lignin biorefinery to produce bio-based polymers
Luana Dessbesell, Nubla Mahmood, Zhongshun Yuan, Mathew Leitch, Reino Pulkki, Chunbao (Charles) Xu

In the search for renewable alternatives to petroleum-derived products to reduce petroleum dependence and industrial footprint, bio-based chemicals and materials have been developed and improved at laboratory scale for many years. Industry, driven by the forest sector, has devoted efforts to develop bio-based chemicals and materials. For example, in 2016 a new commercial demonstration facility started running at West Fraser, Hinton, AB, and a biorefinery investment of $4.5M was announced in Thunder Bay, ON. However, only about 1% of the annually produced lignin has been commercialized for application in bio-based chemicals and materials. There is now on-going work that has resulted in a techno-economic analysis for a kraft lignin (KL) biorefinery (patent to be filed) for the production of bio-based versus petroleum-based polyols and phenols for the manufacture of foams and resins used as insulation and structural materials. The analysis showed the feasibility of the investment. Still, such investment is highly sensitive to variations in the KL cost and bio-based polyol and phenol price. To deal with supply and market uncertainty, a capacity planning model is under development. This model can be a valuable tool for woody biomass biorefinery planning by contributing to the marketing of renewable alternatives for petroleum-based products.

4 - Routing and trail design for soil damage avoidance
Mikael Rönnqvist, Patrik Flisberg, Gert Andersson, Gustav Friberg, Erik Willén

Avoiding soil damage after harvest and forwarding operations is becoming increasingly important in many countries. There are often contractual agreements to avoid damage and in the case it happens, there are often different forms of extra costs and penalties. In order to make a qualitative planning, there is a need of detailed information. The basic information is often provided by airborne laser scanning. This provides detail information on geometry, number of trees, their size and assortments. Another important aspect is so-called water depth maps that describe the amount of level and its depth. The presence of water impacts the vulnerability of the soil against the machine systems. Information on the road system, location of round-wood piles, historical sites and areas selected for preservation is also necessary. With the information described, it is possible to make a pre-plan for the harvesters. However, it is also important to visit and inspect the harvest area in more detail. Often it turns out that some information is not correct and need to be revised. In order to make this re-planning onsite, it is necessary to have a system that can change this GIS information and to make re-optimization fast. In this presentation, we describe such a system developed for use in Sweden. Different versions have been tested the last two years. We describe the results and experiences using them at a set of harvest areas for two larger Swedish forest companies.

■ TB-31

Tuesday, 10:30-12:00 - 304B

Teaching OR/MS 2

Stream: Teaching OR
Invited session
Chair: David Hartvigsen

1 - Deal or no deal: A spreadsheet game to introduce decision making under uncertainty
Timothy Chan

In this paper, we introduce a spreadsheet-based implementation of the game show Deal or No Deal. We describe how this game can be used in class to illuminate topics in decision making under uncertainty to students in both engineering and business. We show that specific scenarios encountered in the game can lead to rich discussions on topics like risk, utility, and probability. The game is easy to learn and play in class and usually receives a strong positive response from students.

2 - The online appointment scheduling game
Antoine Sauré, Martin Puterman

In this talk we describe the online version of the appointment scheduling game (ASG). The ASG is an easy to use teaching tool that reveals the main challenges in managing advance patient scheduling systems and also provides an introduction to simulation and decision analysis. The ASG simulates a system in which daily patient appointment requests, which are characterized by their urgency level, arrive randomly. Daily service capacity is limited. Students playing the game assume the role of a scheduling clerk who must assign appointment dates to these requests without knowing future demand for service. While the game is primarily aimed at undergraduate and graduate operations students, it can also be used to introduce a range of dynamic programming concepts to advanced operations research students. The game has been used successfully in several courses at multiple universities. Instructors can create and simulate multiple system settings, set common random appointment request arrivals, evaluate the performance of alternative patient scheduling strategies, and review and compare the performance of students. Students can play any number of instructor-defined games, see scheduling performance metrics such as service levels and average patient wait times, and review and compare past games to discover better patient scheduling strategies.

3 - Process simulation in the classroom
David Hartvigsen

In this talk we discuss how to incorporate process simulation into introductory or more advanced courses on Operations Research, Operations Management, or Spreadsheet Modeling. Our approach uses SimQuick, which is a freely-distributed Excel-based software package, written by the speaker, for simulating processes such as waiting lines, inventory in supply chains, and manufacturing systems. SimQuick is designed to be easy to learn with clearly defined, simple building blocks that can be combined in a wide variety of ways. Process simulation, using SimQuick, can be covered in a short format (an hour or two of class time), or a longer format.

Tuesday, 13:30-14:30

■ TC-03

Tuesday, 13:30-14:30 - 200AB

Plenary speaker: Egon Balas

Stream: Plenary sessions
Plenary session
Chair: *Dionne Aleman*

1 - Disjunctive programming as a tool for convexifying nonconvex sets
Egon Balas

Linear Programming, born during the last world war, was quickly generalized to convex nonlinear programming; but the lack of convexity turned out to be the stumbling block which separates tractable (i.e. polynomially solvable) problems from intractable ones (whose solution requires exponentially many steps). Nonconvex problems can be reformulated as integer programs, which belong to this intractable class. Disjunctive programming formulates the integrality conditions as disjunctions, and represents the first major inroad into dealing with nonconvexity: disjunctive sets, brought to the form of unions of polyhedra, are nonconvex sets whose convex hull has a compact representation in a space of dimension linear in the number of polyhedra in the union.The disjunctive or lift-and-project approach to cutting plane theory has provided tools that have contributed decisively to the revolution in the state of the art of integer programming that took place starting with the 1990's. In the case of lift-and-project (L&P) cuts from split disjunctions, a correspondence established between bases of the higher dimensional cut generating linear program and those of the original LP relaxation have made it possible to generate L&P cuts directly from the original LP tableau, without recourse to the higher-dimensional representation. This has led to efficient implementations of L&P cuts in public (COIN_OR) and commercial (XPRESS, CPLEX, MOPTA) MIP solvers. Recent research, focused on establishing similar results for L&P cuts from more general disjunctions, has led to rather different conclusions. Namely, while easily verifiable conditions were established for a L&P cut from a general disjunction D to be regular, i.e. equivalent to a standard intersection cut from a polyhedral counterpart of D, in the absence of those conditions the L&P cut, in this case termed irregular, has remarkable properties (like cutting part of the corner polyhedron). Furthermore, far from being exceptional, irregular cuts turn out to be more frequent than regular ones. While irregular L&P cuts cannot be generated by pivoting in the LP tableau, they can be generated as final point cuts from general disjunctions - a recently studied class that promises to bring about an organic synthesis of branch and bound (B&Bd) with cutting plane theory. These cuts are derived from the reverse polar of the disjunctive set defined by the active branches of a B&Bd tree, which can be represented by a set of inequalities in the space of the original MIP. This procedure - more efficient than its L&P counterpart - can be used to capture information from a partial B&Bd tree in the form of cuts valid for the entire tree.

Tuesday, 15:00-16:30

■ TD-01

Tuesday, 15:00-16:30 - 307B

Large scale optimization in air transportation

Stream: Discrete optimization in logistics and transportation
Invited session
Chair: *Francois Soumis*

1 - Constraints aggregation for large-scale pairing problems
Francois Soumis, Mohammed Saddoune, François Lessard

The crew-pairing problem is generally modeled as a set partitioning problem, the flights have to be partitioned in pairings. A pairing is a crew path starting at a base covering many flights during few days of works and finishing at the same base. For large-scale problems a first difficulty is the exponential number of feasible pairing (number of variables). Columns generation permits to deal with it. However solving a master problem of 50 000 constraints at each of the thousands iterations of the column generation request to much time. To reduce the solution time some airlines use a Rolling-Horizon heuristic (RH) that divides the horizon into overlapping time slices. For example two days slices with an overlap of one day. However solving 30 problems of 3000 flights (two days time slices) requires many days and the quality of solutions in not so good because the optimisation is too myopic (the windows are narrow). The Dynamic Constraints Aggregation method (DCA) developed by (Elhallaoui et al. 2005) speed-up the master problem by reducing the degeneracy. This method also produces better dual variables and reduces the number of column generation iterations. Furthermore the LP solution is less fractional and it reduces the number of nodes to explore in the branch and bound. This permits to solve a weekly window of 10 000 flights in few hours. The RH with weekly windows produces solution improved by up to 5% on salaries and reduces the number of deadheads by up to 40%.

2 - Combining Benders decomposition and column generation for solving integrated crew pairing and personalized crew assignment problems
Vahid Zeighami, Francois Soumis

The airline crew scheduling problem, due to its size and complexity, is usually solved in two phases: crew pairing problem and crew assignment problem. A pairing is a sequence of flights, connections, and rests starting and ending at the same crew base. The crew pairing problem consists of determining a minimum-cost set of feasible pairings such that each flight is covered exactly once. In the crew assignment problem, the goal is to construct monthly schedules from these pairings while respecting all safety and collective agreement rules. However, this sequential approach may lead to significantly sub-optimal solutions as it does not take into account the crew assignment constraints and objective during building pairings. In this paper, we propose an extension of the crew pairing problem with additional constraints to incorporate pilot and copilot preference vacations in the crew pairing stage within a completely integrated framework. To solve this integrated problem, we develop a method that combines Benders decomposition and column generation. The solution process iterates between a master problem that represents the crew pairing problem, and two subproblems that represent the pilot and copilot assignment problems as personalized crew assignment problems. We conduct computational experiments with a set of real-life data from a major US carrier.

3 - Considering flight preferences in the airline crew pairings to improve the crew rostering
Frédéric Quesnel

The airline crew scheduling problem is studied by many researchers. Usually, the problem is divided in two steps : the crew pairing problem (CPP) and the crew rostering problems (CRP). While the goal of the CPP is to find feasible pairings at minimum cost, the CRP aims at finding a feasible schedule that satisfy as many employee preferences (preferred airlegs, vacations, etc.) as possible. The main challenge with this approach is that the pairings generated by the CPP may not be suitable for the objective of the CRP. For instance, typical solutions to the CPP contain very few pairings with multiple airlegs preferred by a single crew member, limiting the total number of preferences that can be granted. In order to create pairings that are more compatible with the CRP, we propose a new mathematical formulation for the CPP that favors pairings containing multiple airlegs that are preferred by a single crew member. We show how such model can be solved with column generation, using shortest path problems with ressource constraints as subproblems. Finally, we present results showing the effectiveness of our method.

4 - Airline crew assignment problem solved by branch and price using neighborhood

Salah-eddine Makhloufi, Francois Soumis, Issmail El Hallaoui

The crew assignment problem aims to cover, by crew members monthly covering blocks, every task of the pairings generated in a previous phase. A task represents a crew position on a pairing needing many crew members. We should also respect others constraints like government regulations and collective agreements. The crew assignment problem is a large scale problem solved by branch and price. Its solution is a very time consuming because of many reasons. The dual variable values have strong variation from iteration to iteration, thus, a large diversity of columns and a tailing-off effect. This produces a very fractional LP solution yielding a difficult branch and bound. To shorten the time solution process of a crew assignment software of a specific airline, we propose to use the solution of the cabin manager category (CM) (a small size problem) as set of reference paths (columns) to stabilize the solution of the largest category(FA). We will try to generate, as much as possible, columns in the neighbourhood of these paths. This will reduce the diversity of columns and the number of column generation iterations. It will also produce less fractional solutions and permit to converge rapidly to an integer solution. We experiment our work on instances with up to twenty five thousand pairing tasks and two thousand FA crew members.

■ TD-02

Tuesday, 15:00-16:30 - 308B

Planning of complex manufacturing processes

Stream: Design and management of manufacturing systems

Invited session

Chair: Olga Battaïa

1 - Metaheuristics for the infrared heating in the thermoforming process: A comparison study

Djamal Rebaine, Kahina Bachir Cherif, Fouad Erchiqui, Issouf Fofana

The process of thermoforming usually involves three stages: i) the initial polymeric sheet is oven-heated to a softened state using radiative heat transfer, ii) the heated sheet is deformed into the mold under the action of air flow, and iii) the polymeric sheet cools in the mold. When heated, the plastic sheet is transformed from glassy into a rubbery state. This hot state combined with the gravity creates a non-uniform thickness distribution in the plastic sheet. Adequate optimization of the heating stage can improve significantly the mass distribution in the finished part. One effective way to achieve better uniform thickness distribution is to reduce the differences of energy intercepted and absorbed by the different areas of the thermoplastic sheet. When discretized, the above problem is nothing else than an extended version of the quadratic assignment problem. However, it is known that the quadratic assignment problem is NP-hard. The approximation approach is thus well justified as a solving method. In the present work, we adapt several meta-heuristic algorithms, simulated annealing, migrating bird optimization, tabu search and harmonic algorithms as a solving approach to distribute uniformly the energy intercepted by the material sheet. Then, an extensive experimental study is conducted in order to compare the performance of above meta-heuristic algorithms.

2 - Determination of start times by application of evolution strategies for scheduling in a balanced steelmaking and continuous casting production system

Eduardo Salazar

In the steel making process, the casting stage is critical, because a certain number of charges must be cast continuously on the casting machine. Any interruption at the casting stage causes a (very costly) setup of the machine and may generate scrap from the charges of liquid steel coming out of the converter, so that coordination between converter and casting machine is crucial for the plant efficiency. For a given sequence of batches to be cast producing orders of several steel grades, a meta-heuristic approach by application of evolution strategies to scheduling orders in a balanced steelmaking and continuous casting production system (i.e. equal number of converters as casting machines) is proposed. The schedules are evaluated using the aggregation of fuzzy sets that gives an overall evaluation of the schedule quality by controlling discontinuities and transit times throughout the generations of the evolution strategy algorithm. So, the weakness of meta-heuristic procedures in the determination of processing start times is overcomes by the evolution strategy algorithm to optimize the job start times at the first stage (converter). For illustration purpose, examples of real sized problems are solve, and further research are discussed.

3 - Water-integrated production scheduling in the food industry: A case study in cheese manufacturing

Renzo Akkerman, Sai Jishna Pulluru

Water is an important resource for the food industry, both for production processes, cleaning activities, as well as heating and cooling processes. Many food manufacturers have started to reuse water streams to meet the water demands of these processes, hereby reducing their fresh water requirements as well as reducing their wastewater outputs. A key challenge in these industries is to achieve water management goals without compromising on production efficiency or product quality. In our work, we develop a production scheduling approach for a typical multistage food production system in cheese manufacturing. The approach also integrates water reuse and regeneration options, and includes the development of an industry-specific water quality classification scheme to effectively capture water reuse and water treatment possibilities. We demonstrate the applicability and performance of our approach for the case of a cheese manufacturer that started reusing water streams in production and cleaning activities. We show the trade-offs between the efficient use of the manufacturing equipment on the one hand, and efficient use of water resources on the other hand. Furthermore, we are able to use the scheduling model to provide decision support on the capacitation of treatment equipment. Overall, our framework is able to efficiently plan both production and water reuse and significantly reduce the water footprint of cheese manufacturing and other food production environments.

4 - Sequencing at several-piece-flow assembly lines

Alena Otto, Xiyu Li

Consider a simultaneous lotsizing and scheduling problem arising at paced assembly lines producing highly customized workpieces. Several workpieces, forming a lot, visit serially arranged stations. A lot spends a certain amount of time, called cycle time, at a station. Afterwards, it is moved to the next station with some conveyor mechanism. Although the sets of tasks performed at each station are given, customized workpieces need different processing times at each station. Since workpieces are associated with customer orders, they also have to be processed before their due dates and tardiness should be possibly avoided. We assign workpieces to lots and determine a sequence of lots to minimize the total weighted tardiness, so that the processing time of any lot at any station does not exceed the cycle time. We discuss the motivation behind the optimization problem on several manufacturing examples, set up a model and propose an effective heuristic algorithm.

■ TD-03

Tuesday, 15:00-16:30 - 200AB

Keynote speaker: Julia Bennell

Stream: Keynote sessions
Keynote session
Chair: Janny Leung

1 - Get packing! Key concepts and future directions in cutting and packing problems
Julia Bennell

A huge number of products we use, wear and consume begin as raw material that requires cutting as part of the production process. Clothes, furniture, tools, pipes, shoes and windows are just a few examples. Moreover, the transportation of products efficiently, and safely, require an intelligent methodology for packing and loading taking into account many complex constraints. Cutting and packing problems cover a wide range of applications and with these comes many diverse and interesting challenges. Researchers have been tackling these problems since the 1960s and there is a strong legacy of methodological and application focused contributions. Despite this, there still remains many interesting open problems as well as rich opportunities for working at the interface of cutting and packing with other domains such as transportation and production planning. In this talk I will give a flavour of the diverse scope of cutting and packing problems and discuss some of the emerging application areas. The talk will review some of the key concepts and methodologies used for cutting and packing and highlight some of the current challenges. Moreover, I hope, the talk will enthuse researchers to engage with cutting and packing problems and its research community.

■ TD-04

Tuesday, 15:00-16:30 - 202

Location, logistics, transportation and traffic 3

Stream: Location, logistics, transportation, traffic (contributed)
Contributed session
Chair: Firoz Ahmad

1 - Estimation of moving history information
Sara Hirayama, Masaki Ando, Takashi Hasuike, Shunji Umetani

Nowadays, moving history information is concerned as important data for various real-world applications like urban design and marketing strategy. However, some problems are still remained from the points of privacy protection and reliability by racking and shortage of the moving history information which we apply to various real-world problems. Therefore, this study proposes a mathematical model for the estimation of moving history information of each person using only data of the number of people at each point we set in advance every time period. In this study, Time Space Network (TSN) is used to visualize complicated human movements. The proposed mathematical model is defined as minimizing the total error between the estimated result and the correct data of the number of moving people, inflow and outflow at each point of a subject area. The proposed mathematical model is implemented by using an actual data of moving history information at Tokyo, and the validity is proved. Conclusively, this study achieves the high accuracy estimation of the moving history information holding privacy of each person and reliability of data.

2 - Discrete choice models the Bayesian way: The effect of sample size, number of choice tasks and alternatives
Luiz Lucas, Wagner Esteves, Felipe Souza

Discrete Choice Models - DCMs are ubiquitous in areas such as marketing, medicine or logistics. Amazingly, while bayesian approaches to DCMs are almost the standard in Marketing, usually in Logistics aggregate mlogit models are almost the rule. These aggregate models lack the chance to take into account heterogeneity among respondents and usually need bigger samples than in the hierarchical bayes approach. Our paper compares accuracy for results in simulations derived from sample data with different (i)sample sizes, (ii)number of versions of questionnaire, (iii)number of choice tasks in each version of the questionnaire and (iv) number of alternatives in each choice task. We will generate / simulate hundreds of different "samples' / combinations of the (i)-(iv) possibilities, checking the accuracy for a real world problem for grain exportation through four ports in Brazil: Santos, Paranagua, Mirituba and Itaqui. Since we know the "correct" answer, we can see how different (i)-(iv) combinations perform in terms of accuracy. We think this I very important since in practice the data collection for these logistic models is complicated by the fact that it is not easy to approach more than 20 respondents. That was the case of an mlogit model recently developed by one of the authors for the State of Rio de Janeiro - Brazil

3 - Dispatch optimization in bulk tanker transport operations
Ted Gifford

Schneider National is one of the world's largest for-hire truckload freight carriers. The company executes 10,000 shipments daily with transits ranging up to one week using a fleet of 13,000 tractors and 48,000 trailers. Optimizing the matching of assets (tractors and trailers) to shipments is a complex problem for which solution quality has significant impact on productivity and profitable. A particularly difficult variant of this problem occurs in the Bulk Transport (fuels/chemical) division of the company. This group executes 350 orders per day using a fleet 1000 tractors and 1600 tanker trailers. In the course of a year 10000 distinct commodities may be transported. Chemical interaction properties of these commodities impose complex product-sequencing constraints and inter-order tanker wash and preparation processes as well as selection of specific trailer configurations. These complexities must be considered in addition to those encountered in the standard fleet dispatch problem. The engineering group at Schneider has designed and implemented a multi-phase, multi-dimensional matching algorithm and associated business processes which have lead to significant operational and capital cost savings, as well as improved productivity and customer service. We will describe this solution which is based on a sequence of set covering models with interleaving column generation heuristics.

4 - A transportation problem under non-linear cost function with varying demand and supply
Firoz Ahmad, Ahmad Yusuf Adhami

In this article, a transportation problem has been considered which consists of non-linear cost function due to the extra cost of the remaining quantity at the origins (sources) and has to be supplied to the various destinations (sinks). In real life, many situations encounters in which the supply and demand quantities of goods (products etc.) are not fixed and varies between some specified intervals. So, the study in this paper investigates different kind of mathematical model formulation under non-linear cost function with varying demand and supply. In addition to non-linear mathematical model, a solution procedure has also been discussed. A numerical illustration is also presented in support of the proposed model and solution procedure.

■ TD-05

Tuesday, 15:00-16:30 - 203

Stochastic modeling and simulation in engineering, management and science 2

Stream: Stochastic modeling and simulation in engineering, management and science
Invited session
Chair: *Raik Stolletz*
Chair: *Gerhard-Wilhelm Weber*
Chair: *Parker Servello*

1 - Joint optimization of jobs sequence and inspection policy for a system with a two-stage failure process
Sharareh Taghipour

We consider a single system which is supposed to process n jobs in sequence. The system's failure process has two stages: first a defect arises and if it is left unattended, it will result in an eventual failure. If the system fails while it is processing a job, the job has to be restarted after the system is fixed. The system can be inspected before a job to detect a possible defect. If a defect is present at an inspection, the system is either minimally repaired or replaced according to its age. Corrective and preventive maintenance, as well as inspection and restarting jobs incur costs and downtimes. The objective is to find the optimal jobs sequence as well as the inspection plan for the system to either minimize the expected makespan or the expected total cost.

2 - Dynamic policies for equipment replacement in response to technological innovation
Christopher Kirkbride, *Diego Ruiz-Hernandez*

We consider the problem of replacing or upgrading aging equipment when new or improved technologies enter the market. Technological innovations can be modelled as planned or randomly arriving upgrade releases. The scale of technological advance may be a constant or a random improvement over the previous state of the art for the equipment type. We assume that the cost for purchasing improved technology decreases over time. With each new technological improvement arriving to the market the efficiency or usage of the currently utilised equipment will lag behind the state of the art or become obsolete over time. The manager must plan if, when and how to upgrade or replace the equipment so that it is suitable for its required purpose. When upgrading the manager can choose amongst all co-existing improved technologies available for purchase in the market. The goal of this work is to provide a dynamic policy for upgrading or replacing equipment where, at each decision epoch, the planning actions available are whether to upgrade to an improved technology (or wait for further improvements); and, if so, at what future date (or cost threshold) to upgrade.

3 - A Markov chain Monte Carlo simulation to predict property destination changes in Medellín, Colombia
Julian Andres Castillo Grisales, *Yony Fernando Ceballos*, *Elena Valentina Gutierrez Gutierrez*

Property destinations are key to the identification for cadaster matters, and in the city of Medellín, Colombia, a code system from one to ten is used with that end. In Medellín, such destinations are used to calculate property taxes, and therefore property destination information is essential for the financial sustainability and the planning policies for the city. The ability to identify property destination changes allows to maintain cadaster information up to date. In this work, a Markov chain is established to identify the transition finite-state matrix of property destinations, and then we use Monte Carlo simulation to predict those changes. To do so, we use Medellín cadaster historical information from 2004 to 2016. The results of this work will be used as base information for the cadaster updating process in Medellín for 2017. Moreover, the results allow identifying the urban areas with the larger number of changes, and therefore the definition of the workforce sent to such areas to identify real changes.

4 - An algorithmic approach to optimal evacuation
Parker Servello, *Melvin Quick*, *Esteban Ramirez*, *Erik Vonkaenel*

Buildings, such as hospitals or educational facilities, can, in certain conditions, lack the capacity to handle the flow of people through them. This potentially creates traffic issues in the case of an emergency evacuation. Additions or renovations are commonly proposed to solve this issue but could be avoided by modeling such buildings and optimizing traffic flows. By modeling a local facility, an algorithm can be written which consistently develops optimal emergency routes for the building population. These routes are created in advance, relative to specific times of day. This model also identifies any existing bottlenecks in the system. With respect to the specific time of day, the parameters for this algorithm are obtained via documented arrival and departure times for each room. The model is generalized to be applicable to other buildings given the layout and parameters. This model will assist in the removal of bottlenecks while optimizing traffic flow during times of emergency.

■ TD-06

Tuesday, 15:00-16:30 - 204A

Data driven humanitarian logistics

Stream: Humanitarian logistics
Invited session
Chair: *Erwin van der Laan*

1 - On the design of a relief system of a metropolitan city
Bela Vizvari

This study discusses a top-down approach of the design of a relief system of a metropolitan city. The most serious disaster of a city is an earthquake. The basic concept is that most functions of the relief system are executed by Unmanned Aerial Vehicles (UAV). UAVs can be used for relief distribution, reconnaissance, patrolling, and measuring. The relief items are transported to distribution points covering the city. The transportation consists of waves as the demand changes in time. The system is controlled by the Disaster Command Center (DCC). DCC controls relief distribution, emergency vehicles, and local police. DCC has a multi-technology, and multi-channel communication system. It communicates to the local population, and the units of the relief system. DCC up-dates a data-basis in real time mode. Decisions and information provided to the local population reflect always the latest data. The study discusses the related technologies, both existing and still to be developed, e.g. fast ways to substitute damaged elements of the normal communication system, new mobile applications, finding people under debris. New problems needing mathematical models and methods also arise, like assignment of personnel to operation rooms of hospitals, and real-time minimal path finding in a dynamic environment. The needed capacities and costs are also estimated.

2 - The impact of budget constraint on the interaction between fundraising and procurement decisions
Fuminori Toyasaki, *Emel Arikan*, *Lena Silbermayr*

This research examines the interaction between an aid agency's procurement decision (beforemath-versus-aftermath) and its fund-raising decisions under demand uncertainty in the presence of budget constraints. The aid agency trades off the lower procurement cost of prepositioning against the uncertainty of budget and demand aftermath of a disaster. We investigate how the interaction between the beforemath-versus-aftermath procurement decision and the aid agency's fundraising operation affects its efficacy as well as efficiency.

■ TD-07

Tuesday, 15:00-16:30 - 204B

Inventory routing 1

Stream: Vehicle routing
Invited session
Chair: Amirah Rahman

1 - An adaptive large neighbourhood search heuristic for a deteriorating item inventory routing problem: A case of liquefied natural gas
Yousef Ghiami, Emrah Demir, Tom van Woensel, Marielle Christiansen, Gilbert Laporte

Environmental concerns together with competition between supply chains for more efficient operations have increased the demand for Liquefied Natural Gas (LNG). This is due to lower price for LNG and less emission that it produces compared to the conventional fuel types. In this research work we develop and analyse an adaptive large neighbourhood search (ALNS) heuristic for an inventory routing problem (IRP) that delivers LNG from storage facilities to filling stations. The distribution is performed by a fleet of heterogeneous vehicles. In this study we take into account the deterioration property of LNG that takes place in storage facilities and filling stations. The ALNS developed for this LNG-IRP is then followed by numerical experiments.

2 - Inventory routing and freight consolidation for perishable goods
Maged Dessouky, Weihong Hu

Our study focuses on improving the competitiveness of supply chains by jointly managing transportation, inventory and consolidation. More specifically, we integrate two problems that are typically solved independently. The first decision is the determination of the shipments and routes from the growers to the consolidation center, which is the short-haul problem and can be modeled as an inventory routing problem(IRP). The second decision is the shipments from the consolidation center to the retailers or wholesalers, which is the long-haul problem. The standard approach is to first solve the consolidation decision (long-haul problem) since it is typically the more costly element, and then use the solution as the demand for the short-haul problem (IRP). However, our results show that the overall costs can be reduced by utilizing an integrated system-wide optimization approach for solving the problem.

3 - Adaptive large neighbourhood search heuristic for the cold chain routing problem
Amirah Rahman, Joshua Ignatius, Seyyed-Mahdi Hosseini-Motlagh, Parizad Vakili

The Inventory Routing Problem integrates inventory allocation with the Vehicle Routing Problem where the supplier is responsible for replenishment policies and routing plan under the vendor managed inventory strategy. We study a deterministic Inventory Routing Problem in a cold chain that delivers two types of products: temperature sensitive products (needs refrigeration), and non-temperature sensitive products. All products have fixed maximum shelf lives. The products are to be delivered to customers by a homogeneous fleet of vehicles with both refrigerated and unrefrigerated compartments. We assume that the customers have the capacity to hold both refrigerated and unrefrigerated inventory. In this talk, we will discuss the problem formulation and the Adaptive Large Neighbourhood Search heuristic that we use to solve our problem.

■ TD-08

Tuesday, 15:00-16:30 - 205A

Revenue management

Stream: Revenue management and pricing
Invited session
Chair: Meisam Soltani-koopa

1 - Enhancing customers' segmentation: Targeting and quality differentiation
Amit Eynan, Benny Mantin

We consider a manufacturer who sells to a diversified customer population. Customers are heterogeneous with respect to their valuation of quality, and therefore, with their willingness to pay, as well. Thus, the manufacturer is being challenged with identifying the optimal profit-maximizing quality and price of the product. Due to trade-offs the manufacturer's dilemma is whether to offer a high quality, high price product which will appeal to a small group of high quality seeking customers who are willing to pay handsomely, or offer a lower quality product at a lower price in order to attract more customers and boost demand. We study two strategies that the manufacturer can employ to mitigate this dilemma and increase profit: (i) segment the market by offering coupons to targeted customers and sell the product at multiple prices, and (ii) segment the market by offering two vertically differentiated products at two prices and allow customers to self-select the product that provides them with the highest utility. Furthermore, we combine the two strategies to achieve additional segmentation and find that, most often, offering targeted coupons, the manufacturer should not modify the products' qualities. Because quality decisions are long terms this insight assures the manufacturer that quality decisions may be made effectively even if targeting efforts decisions are still yet to be determined.

2 - Products closing times optimization for choice-based revenue management
Thibault Barbier, Gilles Savard, Miguel Anjos, Fabien Cirinei

Choice behavioral aspect is now paramount to network revenue management. Tackling both "buy-up" and "buy-down" phenomena, choice-based models provide more accurate and robust solutions, thus generating better revenue. Most choice-based models optimize revenue by adjusting how much time each set of products must be offered over the booking process. This approach was introduced by the choice deterministic linear program (CDLP) and has been extensively developed since then to reduce resolution time and to tackle different choice behavior. We offer a new approach for choice-based network revenue management that finds when to stop selling each product during the booking process. Numerical experiments on literature instances demonstrate promising performance. Our model quickly returns a directly implementable control that often gives better revenue when simulated than traditional products sets approaches.

3 - A lifetime-value of a liquidity-constrained retailer
Meisam Soltani-koopa, Yuri Levin, Mikhail Nediak, Anton Ovchinnikov

Trade credit typically appears as a grace period for invoice payment. It helps retailers overcome temporary cash shortages as an alternative to seeking financing from banks. We consider a supply chain with one supplier and one repeated newsvendor retailer who is liquidity-constrained but has a line of credit from a bank. In each period, the retailer decides about the quantity to order and how much credit to use from the line of credit. We study the profit to go function and the optimal policy of the retailer to maximize the retailer profit considering the discounted future profit in a finite horizon. We also consider the optimal terms of the supplier-retailer contract.

■ TD-09

Tuesday, 15:00-16:30 - 205B

IFORS: Panel discussion with the administrative committee

Stream: IFORS sessions
Panel session
Chair: Michael Trick

1 - IFORS: Panel discussion with the administrative committee
Richard Hartl, Luciana Buriol, Karla Hoffman, Graham Rand, Elise del Rosario, Sue Merchant, Guillermo Durán, Nelson Maculan, Jacek Blazewicz, Chang Won Lee

What role does IFORS play as an organization supporting operational research and OR societies around the world? The Administrative Committee will discuss current and future directions for IFORS in a panel format. There will then be a general discussion of new activities and opportunities.

■ TD-10

Tuesday, 15:00-16:30 - 205C

Multiobjective optimization methods with applications

Stream: Multiobjective optimization methods and applications
Invited session
Chair: Tadeusz Trzaskalik

1 - A new method for continuous multi-objective weather routing based on combination of multi - and single objective methods
Kateryna Mishchenko, Mats Molander

The problem concerns optimal weather routing for sea going vessels. The objectives are min total travel time, total amount of fuel consumed and discomfort factor for passengers. The problem is solved subject to set of limitations on the fuel, speed of the vessel, and other. This paper presents the new method for updating a solution from the multi-objective optimization. It combines the strong features of the MOO and SOO methods to provide the efficient and fast update of the routes and can be used online by the crew with the full control over the choice of the compromise routes. Firstly, the MOO problem corresponding to the initial weather forecast is solved using the Dynamic Programming and one or several Pareto optimal solutions are selected by the user. Each of these reference solutions transforms into a single-objective optimization criteria. Such SOOP are introduced to reflect the chosen reference solutions. These new problems are solved each time a new weather forecast or other data are available. For large changes in weather conditions the SOOP may become infeasible with respect to some constraints, e.g. fuel consumption. In this case the optimal routes are recalculated as the new weather forecast is available. To speedup computations, parallel computations are used. The numerical experiment with 596 Pareto optimal solutions on the final stage obtained by the MOOP gives CPU time equal to 5 hours. Solution of the correspondent SOOP takes 9.4 min with as good solution.

2 - Sensitivity analysis for multiple criteria decision making problems
Stanislaw Walukiewicz

Using duality theory, the well known regularity conditions and sensitivity analysis for linear programming problems are presented to write a multiple criteria decision making (MCDM) problem in a similar format. Next the duality gap for a given MCDM problem is defined, as well as the construction of a linear boundary between feasible and definitely infeasible values of the objective function, i.e. corresponding points in the outcome space, is described. A ray from the ideal element perpendicular to the linear boundary forms a base for a new parameterization of a given MCDM problem, and it is a starting point for a discussion on sensitivity analysis and regularity conditions for such problems. A rationale for our approach with its geometrical interpretation is provided and explained by a numerical example. Finally, a sequential modeling method in MCDM as the main result is presented, pointing out its similarity with a single criteria optimization. We also compare our approach with the other parameterization methods known in the literature, and illustrate it with preliminary results for selecting portfolios of international investment funds.

3 - Interior point methods applied to the predispatch hydroelectric system with modification in the network topology and spinning reserve
Silvia Maria Simões Carvalho, Aurelio Oliveira, Mayk Coelho

Specially designed primal-dual interior point methods for minimization of generation and transmission loss of a hydroelectric predispatch power system with network topology change and service reserve anciliar additional constraints was developed. The resulting matrix structure will be exploited aiming to an efficient implementation. The implementation to be performed was compared with an existing one, that does not consider either topology change or additional constraints, regarding both: the solution features and computational performance.

4 - Quasi-hierarchical method for discrete multiobjective stochastic dynamic programming problems
Tadeusz Trzaskalik, Maciej Nowak

In this paper we consider a multi-stage, multi-criteria discrete decision process under risk. We use a discrete, stochastic dynamic programming approach based on Bellman's principle of optimality. We assume that the decision maker determines a quasi-hierarchy of the criteria considered; in other words, he or she is able to determine to what extent the optimal expected value of a higher-priority criterion can be made worse to improve the expected value of a lower-priority criterion. The process of obtaining the final solution can be interactive. Based on the observations of the consecutive solutions, the decision maker can modify the aspiration levels with respect to the criteria under consideration, finally achieving a solution which satisfies him/her best. A numerical example is presented to illustrate the applicability or the method.

■ TD-11

Tuesday, 15:00-16:30 - 206A

Supply chain coordination 1

Stream: Supply chain management
Invited session
Chair: Bhavin Shah

1 - Flexible capacity strategy in an asymmetric oligopoly market with competition and demand uncertainty
Liu Yang, C.t. Ng

This talk established an asymmetric oligopoly competition model consisting of flexible capacity strategy (FCS) and inflexible capacity strategy (IFCS) under demand uncertainty. All firms carry out a decision-making operation process spanning stages of capacity, production and pricing. The difference between the two strategies is that FCS enables firms to postpone production decisions until observing the actual demand, whereas IFCS does not. We analytically characterize the unique Nash equilibrium. It is shown that the two strategies co-exist only under certainty conditions. We reveal that although flexible and inflexible firms are of different capacity strategies, they follow the same mechanism in determining capacity investment decisions. We have found under certainty conditions, an increasing competition intensity of inflexible (flexible) firms damages the flexible firms' affordability of capacity investment and force the flexible (inflexible) firms to quit the market. Interestingly and surprisingly, we have found that an increase in production cost benefits flexible firms when enough inflexible firms exist in the market, but is always harmful to inflexible firms. Furthermore, we identify there is a unique costing threshold to determine the optimal strategy in the two-strategy co-existing competition.

2 - Supply chains for public-interest goods
Nesim Erkip, Ece Demirci

Public-interest goods create benefits to individual consumers as well as non-paying third parties. When such positive externalities exist, the good may be under-produced or under-supplied due to incorrect policies or failing to value external benefits and hence a need for intervention arises. We consider a social planner who intervenes so that the adoption level of the product is closer to the socially desirable level. The social planner seeks to design and finance an intervention strategy that will impact the decisions of the channel in line with the good of the society, specified as social welfare. We consider intervention tools that can target the supply or demand of the good. One option for the intervention tool is investment in demand-increasing strategies. Second option is investment in strategies that will improve supply: rebates or subsidies, production yield-improving strategies are examples. We present two cases: California electric vehicle market and US influenza market. As several real life cases indicate, central authority operates either under a limited budget or optimizes her budget. We introduce and analyze social welfare maximization models with the emphasis on optimal budget allocation (or with selecting optimal budget level). We utilize bi-level programming for modeling the role of social planner, as well as incorporating other actors in the supply chain. We use real-life data and information to show the benefits of using the proposed mathematical models.

3 - Coordination on improvement of the supplier: The role of the buyer on managing investment
Amirmohsen Golmohammadi, Elkafi Hassini

We study joint investment by a buyer and a supplier in improving the supplier's capacity using a Stackelberg game model, where the buyer is the leader, and supply and demand are uncertain. We show that the players have an opportunistic behaviour toward investment. When the buyer finds that the supplier is motivated enough to invest, he avoids any direct contribution on capacity improvement. In this situation the buyer follows an order inflation strategy to increase the investment of the supplier. However when the supplier does not show the desire to make enough investment, the buyer will engage in direct investment in the supplier's capacity. We also considered the role of order inflation, price-only, investment sharing and penalty cost contracts in coordinating the supply chain. Finally, we looked at two extensions where the supplier is the leader and when the buyer uses an order-postponement strategy.

4 - Efficacy of price discounts, effort sharing and direct promotion as supply chain co-ordination mechanisms
Bhavin Shah, Gopalan Srinivasan

This paper investigates efficacy of various policies such as price discounts, effort sharing and direct promotion as supply chain co-ordination mechanism. It explores co-ordination alternatives for both centralized as well as decentralized supply chain under price and effort dependent stochastic demand. Paper further discusses implications from the perspectives of manufacturer, retailer and the consumer.

■ TD-12
Tuesday, 15:00-16:30 - 206B

Meet the editors of EJOR on its 40th anniversary

Stream: EJOR special session
Invited session
Chair: Roman Slowinski

1 - Some facts about the current status of the European Journal of Operational Research (EJOR)
Roman Slowinski, Immanuel Bomze, Emanuele Borgonovo, Robert Dyson, José Fernando Oliveira, Ruud Teunter

The editors of EJOR will present some facts about the journal, characterizing its current status and relative position in the rankings of journals from the field of operational research (OR) and management science (MS). These facts are based on 2016 data from Elsevier's production report, and on IF'2016 rankings of OR&MS journals by Web of Science and SCOPUS. In the last part of the session, the editors will answer some general questions from the audience.

2 - Forty years of the European Journal of Operational Research: A bibliometric overview
José M. Merigó, Sigifredo Laengle, Jaime Miranda, Roman Slowinski, Immanuel Bomze, Emanuele Borgonovo, Robert Dyson, José Fernando Oliveira, Ruud Teunter

The European Journal of Operational Research (EJOR) published its first issue in 1977. This paper presents a general overview of the journal over its lifetime by using bibliometric indicators. We discuss its performance compared to other journals in the field and identify key contributing countries/institutions/authors as well as trends in research topics based on the Web of Science Core Collection database. The results indicate that EJOR is one of the leading journals in the area of operational research (OR) and management science (MS), with a wide range of authors from institutions and countries from all over the world publishing in it. Graphical visualization of similarities (VOS) provides further insights into how EJOR links to other journals and how it links researchers across the globe. The work uses computer software for the visualization process by collecting the bibliographic material and building networks in terms of co-occurrence, co-citation and bibliographic coupling.

3 - Publishing research in OR - The perspective of EJOR editors
Robert Dyson, José Fernando Oliveira

Trying to publish a paper in a highly regarded journal such as EJOR may sometimes be a negative experience for the authors, due to several reasons, from lack of fit regarding the journal quality standards to a poor fit to the scope of the journal. But even when the paper reports good research within the scope of OR, the process may go wrong due to the lack of understanding about the review and publishing process overall. Therefore, in this talk we will present a set characteristics to help to understand the requirements for a good research paper. We then go through some formal aspects of the reviewing process under the assumption that a good way to learn how to write a good paper is to understand how it is reviewed i.e. to look at the other side of the mirror. Some hints on how to correctly structure a paper and how to answer to reviewers will also be given. To publish in highly regarded journals quality is a (very much) necessary condition, but not sufficient.

■ TD-13

Tuesday, 15:00-16:30 - 207

Scheduling applications

Stream: Scheduling problems in logistics
Invited session
Chair: *Cristina Núñez-del-Toro*

1 - Periodic event scheduling and its application in manufacturing systems
Tobias Hofmann

The employment of industrial robot systems in the automotive industry noticeably changed the view of production plants and led to a tremendous increase in productivity. Nonetheless, rising technological complexity, the parallelization of production processes, as well as the crucial need for respecting specific safety issues pose new challenges for man and machine. Furthermore, the progress shall proceed – production cannot be too fast, too safe or too cheap. Our goal is to develop algorithms, guidelines and tools that make the commissioning of industrial robot systems more dependable by verifying the programs of robots and logical controllers. This in particular includes optimizing the schedule of the robot systems in order to ensure desired period times as well as conflict free timetables already in the planning stage. The talk will be about the periodic event scheduling problem proposed by Serafini and Ukovich in 1989 as well as its cycle periodicity formulation. In order to obtain a suitable formulation with a small number of integer offset variables it plays a crucial role to choose an appropriate cycle basis of the underlying precedence graph. Our actual research focuses on the latter aspect. We identified appropriate cycle bases as well as admissible bounds for the remaining integer offset variables.

2 - Practical extensions for the twin robots scheduling problem
Andreas Wiehl, Florian Jaehn

Many industrial sectors rely on robots for efficiently execute storage and retrieval jobs. Practical application are, for instance, warehousing operations in automated storage and retrieval systems and container logistics at seaport terminals. We present a detailed look on the NP-hard Twin Robot Scheduling Problem (TRSP), in which two robots are required to perform jobs at given positions along a rail with a non-crossing constraint. The objective is to minimize the make-span. We present practical problem extensions, approximation algorithms and a numerical study.

3 - Crop scheduling of plant factory with considering multi-period harvest
Chao-Lung Yang, Kwei-Long Huang, Chia-Wei Kuo

Plant factory is an environmental controlled facility which can sustain the stable crop cultivation with fast production and better quality by optimizing temperature, humidity, lighting, nutrient supply and other cultivating factors. In this study, we focus on the crop-scheduling problem for a plant factory and consider harvesting crops with multiple periods instead of one-time gathering. The crop cultivation schedule is formulated as a mixed integer programming (MIP) problem. The objective is to find the maximum profit for the plant factory under the constraints of different practical conditions including types of crops, cultivation room number, cultivation room space, heterogeneous harvesting amount among different environment of cultivation room and multiple-period harvesting. This study develops a heuristic algorithm by utilizing Lagrangian relaxation method to solve the problem to solve the problem effectively for a large-scale production.

4 - A branch-and-price algorithm for the aperiodic multi-period service scheduling problem
Cristina Núñez-del-Toro, Elena Fernandez, Jörg Kalcsics

This work considers the multi-period service scheduling problem with an aperiodic service policy. In this problem, a set of customers who periodically require service over a finite time horizon is given. In order to satisfy the service demands, a set of operators is given, each with a fixed capacity in terms of the number of customers that can served per period. With the aperiodic policy, customers may be served before the period when the service would be due. Two criteria are jointly considered in this problem: the total number of operators, and the total number of ahead-of-time periods. The task is to determine the service periods for each customer in such a way that the service requests of the customers are fulfilled and both criteria are minimized. A new integer programming formulation is proposed, which outperforms an existing one. Since the computational effort required for obtaining solutions considerably increases with the size of the instances, we also present a reformulation suitable for column generation, which is integrated within a branch-and-price algorithm. Computational experiments highlight the efficiency of this algorithm for the larger instances.

■ TD-14

Tuesday, 15:00-16:30 - 305

Sustainable food logistics

Stream: Sustainable logistics
Invited session
Chair: *Jacqueline Bloemhof*
Chair: *Saman Hassanzadeh Amin*

1 - Assessing eco-efficiency of alternative biorefining technologies in agri-food supply chains
Argyris Kanellopoulos, Jochem Jonkman, Jacqueline Bloemhof

To remain competitive, current agri-food supply chains must become eco-efficient which implies that they will have to maximize productivity while minimising their environmental burden. Biomass and side streams which currently are considered waste should be valorized efficiently. Modern biorefining technologies provide feasible alternative production possibilities that enable production of biomass-based products like bioethanol and biogas from crop residues. Their implementation also allows for alternative supply chain configurations. The capacity of these technologies to improve eco-efficiency of agri-food supply chains must be evaluated quantitatively before implementation. Diffusion of these technologies depends on the way benefits are distributed to the involved links of the supply chain. This implies that important decisions at strategic and operational level in different links of the chain must be taken into account explicitly. We develop a multi-objective Mixed Integer Linear Programming model to optimize decision making at farm and processing level of the sugar supply chain in the Netherlands. Optimal solutions at chain level led to unattractive decisions for individual decision making units. Therefore, a set of eco-efficient solutions was calculated, taking into account cost or benefit sharing between the decision making units considered. Financial incentives for individual decision making units affect the overall eco-efficiency performance of the entire chain.

2 - Sustainable supply chain design in the food system with dietary considerations: A multi-objective approach
Sonja Rohmer, G.D.H. (Frits) Claassen, J.c. Gerdessen, Pieter van 't Veer, Jacqueline Bloemhof

Current food production and consumption patterns in combination with a growing world population put pressure on our environment and pose a serious threat to the food security of future generations. While food remains essential for every day survival and should be affordable for everyone, this unsustainable development necessitates a rethinking of dietary provision and the food system behind it. Abundance of choice, highly interlinked products and globalisation, have, however, heavily impacted the complexity of the system and made individual food supply chains less transparent. The environmental impact of a product is thus not only defined by the product itself but often depends on many other factors, such as transport and processing aspects and can vary significantly depending on the production location. This research aims to propose an integrated network design problem for the food system under consideration of nutritional demands, incorporating sourcing, processing and transportation decisions within a network of multiple interrelated food supply chains. While the minimisation of different environmental impact indicators (i.e. land use, water use, energy use, climate change etc.) builds the core of this research, cost minimisation still plays a significant role in supply chain configurations of food, thus requiring a multi-objective modelling approach.The findings of this research are illustrated based on a nutritional case study and through use of real-life LCA data.

3 - The load dependent vehicle routing problem for temperature controlled road transportation
Heleen Stellingwerf, Argyris Kanellopoulos, Jacqueline Bloemhof, Jack van der Vorst

Temperature controlled transport is used to maintain quality of products such as fresh and frozen foods and pharmaceutics. Road transportation is responsible for a considerable part of global emissions, and temperature controlled transportation exhausts even more emission than ambient temperature transport because extra fuel is needed to provide the energy for cooling. The transportation sector is under pressure to improve both its environmental and economic performance. To explore opportunities to reach this goal, the Load Dependent Vehicle Routing Problem (LDVRP) has been developed. However, this approach does not take into account the environmental effects of temperature regulation. Therefore, this paper proposes an extension of the LDVRP to account for thermal energy need as well. This extended LDVRP is applied in a case study in the Dutch frozen food industry. Our results show that taking into account energy needed for temperature control can result in different optimal routes and speeds compared to the LDVRP and the VRP. Also, it shows that taking into account thermal energy requirement can improve the estimation of fuel consumption and emissions related to temperature controlled transport.

4 - Design and optimization of a bottled water forward and reverse supply chain network
Saman Hassanzadeh Amin, Pezhman Papen

A closed-loop supply chain includes both forward and reverse supply chains. In this talk, design and optimization of a closed-loop supply chain network is described focusing on bottled water as the product. The objective function is maximization of the profit. We develop a mixed-integer linear programming model to solve this problem. In addition, the model is developed to consider multiple objectives. The application of the proposed mathematical model is shown in Montreal, Canada using real locations.

■ TD-15

Tuesday, 15:00-16:30 - 307A

Nonconvex optimization and methods

Stream: Continuous optimization (contributed)
Contributed session
Chair: Yi-Shuai Niu

1 - Double bundle method for nonsmooth DC optimization
Kaisa Joki, Adil Bagirov, Napsu Karmitsa, Marko M. Mäkelä, Sona Taheri

A class of functions presented as a difference of two convex (DC) functions constitutes an important subclass of nonconvex functions, since these functions preserve some important properties of convex functions. In addition, many practical problems can be expressed in a DC form such as location planning, engineering design and cluster analysis. However, a stopping condition used in most nonsmooth DC algorithms guarantees only criticality for the solution point and this condition is weaker than Clarke stationarity typically used in general nonconvex nonsmooth optimization. We will introduce a new double bundle method for unconstrained nonsmooth DC minimization utilizing explicitly the DC decomposition of the objective. The main focus is on a new stopping procedure designed to ensure Clarke stationarity for candidate solutions by using only information about the DC components. In addition, if a candidate solution is not Clarke stationary, then the stopping procedure yields a descent direction. In practice, this means that we are able to avoid some drawbacks encountered when criticality is used as a stopping condition. Some encouraging numerical results will also be presented.

2 - Hyperbolic smoothing method applied to the problem of covering solid bodies with equal spheres
Helder Venceslau, Daniela Lubke, Vinicius Layter Xavier, Adilson Elias Xavier

We consider the problem of optimally covering solid bodies using a given number of equal spheres. The mathematical modelling of this problem leads to a min-max-min formulation which, in addition to its intrinsic multi-level nature, has the significant characteristic of being non differentiable. The application of the Hyperbolic Smoothing Method results in a simple one-level non-linear programming problem which allows overcoming the main difficulties presented by the original one. To illustrate the performance of the method we present computational results for the covering of a ring torus, whose optimal solution is known whenever the number of covering spheres is small.

3 - On DC decompositions and DC algorithms for polynomial optimization
Yi-Shuai Niu

Polynomial optimization is a special case of DC (Difference of Convex functions) programming since it can be equivalently represented as a nonconvex quadratic programming that is indeed a DC programming. While different kinds of DC programming formulations yield different DC algorithms. In this talk, we will focus on various DC decomposition techniques for representing a polynomial function as a DC function (such as different of sos-convex polynomials, DC decomposition for homogeneous function, DC decomposition for quadratic function etc.) and finally derive some DC programming formulations for polynomial optimization. We can then use a well-known and efficient algorithm-DCA for local optimization. In combination with global optimization techniques such as Branch-and-Bound and SDP relaxations for polynomial optimization, hybrid global optimization algorithms for solving general polynomial optimization will be also proposed.

4 - Acceleration of Uzawa method for quadraic programming in contact mechanics
Yoshihiro Kanno

The Uzawa method is a classical method for solving optimization problems with inequality constraints. It is still quite often used in computational contact mechanics, i.e., computation of deformations of solids that can possibly touch each other. Suppose that an elastic solid is subjected to a static load, and can touch a fixed rigid obstacle. Under the assumptions of the small deformation and the frictionless contact, it is known that the problem finding the equilibrium state (i.e., the deformed configuration) of the solid can be recast as quadratic programming (QP). Although any efficient algorithm, e.g., an interior-point method, can certainly be used to solve the QP, the Uzawa method is often preferred in contact mechanics because it can be implemented very easily by using a conventional finite element analysis code. Major drawback of the Uzawa method is its slow convergence. This paper presents an acceleration scheme of the Uzawa method. It is known that the Uzawa method can be viewed as a projected gradient method applied to the Lagrangian dual problem. The acceleration scheme presented in this paper is regarded as application of Nesterov's one to this projected gradient method. Preliminary numerical experiments suggest that the proposed acceleration, combined with an adaptive restarted scheme, speeds up the convergence of the Uzawa method.

■ TD-16

Tuesday, 15:00-16:30 - 308A

MCDM / MCDA DSS

Stream: Decision support systems
Invited session
Chair: *Caroline Mota*
Chair: *Adiel Teixeira de Almeida*

1 - Multi-criteria model to identify vulnerable areas: An application in a Brazilian context
Debora Pereira, Caroline Mota, Martin Andresen

Violence is a global problem, but primarily in developing nations. Countries such as Brazil have been trying to reduce their crime rates for many decades, both with and without success. Although Brazil had made many efforts to reduce crime in recent years, the number of homicides continues to grow. Therefore, despite these efforts, Brazil has been unable to increase public security, even though many programs have been applied all over the country. Changing this scenario is a complex task. It is not only a question of choosing the best actions, but where these actions are to be assigned. In this Brazilian context, we present a decision-making model that aims to identify the most vulnerable areas for homicides in a neighborhood. We considered social, economic, and demographic variables to analyze critical zones, using a multi-criteria approach and grouping analysis. The identification of these areas may help in public security planning, because resources are limited and must be prioritized. Our analysis contributes to public security planning in at least four distinct ways: (1) it considers the preferences of a decision maker; (2) it takes into account many criteria; (3) it involves a spatial component; and (4) it contemplates the vulnerability of the surroundings.

2 - Map-based multicriteria analysis to support stakeholder-oriented urban energy scenarios
Sara Torabi Moghadam, Patrizia Lombardi, Jacopo Toniolo, Francesca Abastante, Isabella Lami

The choice among urban energy planning scenarios is extensively based on multi-actors and multi-criteria aspects. Hence, the stakeholders-oriented approach plays a key role in implementing the effective strategies for regional adaptation. An on-going national project, named "Zero Energy Buildings in Smart Urban Districts", emphasizes the use of a Multicriteria Spatial Decision Support System (MC-SDSS) to provide communicative support among workshop's participants. This allows making an explicit trade-off between stakeholders' preferences. The demonstration is the city of Settimo Torinese, in the metropolitan area of Turin, Italy). This study aims at presenting the on-going research activities with a specific focus on the definition of different energy scenarios for Settimo Torinese, based on stakeholders' preferences. A first focus group was organized to select the criteria and to assign the stakeholders' preferences using the "playing card" method of Simos 1990. Accordingly, three decision scenarios have been developed. Each scenario represents a set of retrofitting measures basing on different hierarchy of preferences of the stakeholders as environmental-oriented scenario; economical-oriented scenario; mixed-rationalization scenario. In this regard, the MC-SDSS was tested during a second workshop as part of the urban energy planning process to choose the best energy scenario through a Multicriteria method, the Analytic Hierarchic Process.

3 - Decision aid with partial information using FITradeoff for preference elicitation
Adiel Teixeira de Almeida, Eduarda Frej, Rodrigo José Pires Ferreira

Decision makers' preference elicitation is one of the most important concerns in multicriteria decision making/aid (MCDM/A) processes. The facilitation process demands contributions in the junction of several topics, such as: cognitive process of individuals, analytical modeling and so forth. The use of FITradeoff (Flexible and Interactive Tradeoff) is presented for preference elicitation with partial information, emphasizing its flexible feature. FITradeoff works within MAVT scope for preference elicitation for additive models and is built on classical tradeoff procedure. Behavioral studies have shown inconsistences during elicitation, when using the classical tradeoff procedure. On the other hand, this is one of the procedures with strongest theoretical foundation. Applications are shown in order to illustrate how the FITradeoff methods contribute for reducing inconsistences in the process.

4 - Flexible and interactive DSS for ranking problematic
Eduarda Frej, Adiel Teixeira de Almeida

This work aims to show a decision support system for ranking problematic based on the multicriteria decision method FITradeoff. The Flexible and Interactive Tradeoff is a new method for elicitation of criteria weights in additive models (MAVT). An illustrative application will be presented in order to show how de DSS works. FITradeoff DSS is available for download on request at www.fitradeoff.org/download. The authors would like to acknowledge CNPq for the financial support for this research.

■ TD-17

Tuesday, 15:00-16:30 - 309A

DEA and performance measurement 4

Stream: DEA applications
Invited session
Chair: *P. Matthias Takouda*

1 - Benchmarking the benchmarks - Comparing the accuracy of Data Envelopment Analysis models
Sebastian Kohl, Jens Brunner

Data Envelopment Analysis (DEA) is one of the most popular benchmarking techniques to assess the efficiency of companies or organizations. It identifies "best practices" and compares the performance of all companies to the resulting best practice frontier. Areas of application are among others, banking, healthcare, education, transportation and agriculture. Since its invention in 1978, lots of different model developments have emerged. Yet it is unclear, which of those models delivers the most accurate results and should therefore be the first choice for the computation of efficiency. To overcome this gap, we developed a benchmark based on Monte Carlo simulation data that combines multiple performance indicators and delivers robust results on the performance of different DEA models.

2 - Applying Data Envelopment Analysis to identify vacuum parameters of brake fluid filling machine for preventing brake test failure
Kun-Ping Cheng, Chang Dong-Shang, Rouwen Wang

The vacuum level before filling brake fluid in the automotive production can affect the performance of braking force. In practice, the leakage test of vacuum involves positive pressure test and negative pressure test. According to vehicle safety standard, the performance of brake force should include the total braking force, balance force and hand brake power. This study firstly investigates the effect of vacuum parameters on brake force performance by data analytic from braking test. In order to prevent the failure from brake test in production, the boundary of vacuum leakage parameters have to be further explored. Therefore, this study employs data envelopment analysis to identify the bounding of vacuum parameters that achieving worst frontier of brake force. A non-oriented Slack Base Model (SBM) is developed, which treats the vacuum leakage parameters as the output variables and braking force indicators as the input variables The results contribute to the development of automatic detection system for preventing the failure from brake test.

3 - DEA in the Canadian mining industry: A case study
P. Matthias Takouda, Mohamed Dia, Kobana Abukari, Abdelouahid Assaidi

In Canada, the mining industry is one of the most important sectors of the economy. In this study, we assess the operating efficiency of Canadian publicly listed mining firms. Our methodology is based on Data Envelopment Analysis, completed with appropriate statistical analysis. We consider a sample of 30 listed Canadian mining firms, which has incurred positive operating profits during the period 2011-2015, Using the classic CCR and BCC models, we compute the overall technical, managerial and scale efficiencies scores of the sample. Our findings indicate that the firms exhibit weak technical efficiencies, essentially due to managerial inefficiencies. Further, a steady decline of the technical and managerial efficiencies scores is observed during the period of study. At the sectorial level, general mining companies have, in average, the best score for the management of their operations. On the other side, firms mining gold, diamond, gemstones, platinum & other precious metals performed the best when it comes to scale of their operations. Finally, we identify benchmarks for the individual firms and provide managerial insights into means to improve their efficiencies.

■ TD-18

Tuesday, 15:00-16:30 - 2101

Classification problems

Stream: Data science and analytics (contributed)
Contributed session
Chair: Sofie De Cnudde

1 - An efficient geometric approach for one-class classification with enhanced interpretability and classification accuracy
Jin Young Choi

Recently, the importance of one-class classification problem becomes more increasing. However, most of classification methods such as support vector machine (SVM) and decision tree have the limitation on providing the interpretability of the classification results and classification accuracy. Motivated by thess remarks, this paper suggests a new efficient geometric approach for one-class classifier using hyper-rectangle discriptors (HRDs) that can be made from intervals including observations. Pursuing this purpose, we consider two approaches: (i) top-down approach and (ii) bottom-up approach. For the bottom-up approach, we first generate intervals for each feature and then produce hyper-rectangles by integrating them, where the length of intervals can be parameterized. Top-down approach makes maximum interval for each feature and divide it into sub-intervals. HRDs constructed for a given data set define a classification model. During this procedure, we can also extract patterns that a data set originally has, which can be used for characterizing the data set. In contrast to main one-class classifiers such as SVM and neural network, the suggested methods can provide the reason about the classification results using HRDs. We compute classification accuracy of those two methods using area under the ROC curve and show the superiority of the suggested methods by comparing them with other one-class classification algorithms using datasets from UCI machine learning repository.

2 - Optimal risk bounds for multi-class supervised classification
Loubna Benabbou, Pascal Lang

We examine multiclass classification problems with valued asymmetric loss functions, reflecting unequal gravity of misclassification. The generalization error of a classifier is viewed as its expected loss. While this risk is unknown, it can be assessed via a non-parametric upper bound. We first establish a reduction principle which makes it possible to represent the multiclass classification in a compact form. We then formulate a mathematical program that yields the tightest possible bound. Due to a pseudo-convex constraint, a special method of centers is used to solve this problem.

3 - A norm-ball covering approach to the one-class classification
Sehwa Kim, Kyungsik Lee, Young-Seon Jeong

One-class classification (OCC) is a supervised learning technique for classification, where the classifier is constructed only by training the objects in the target class and determines whether new ones belong to the class or not. In this paper, we present a novel approach to OCC, which is based on the optimal covering of the target objects by 'good' norm balls. We propose an integer programming model for the selection of the optimal norm balls. The classifier consists of a set of norm balls covering the objects in the target class; an object is classified in the target class if at least one or more norm balls contain it. Computational experiments were carried out to test the overall performance of the obtained classifier using some data from the UCI Repository. Also, the performance of our classifier was compared with that of other OCC classifiers.

4 - A benchmarking study of classification techniques for big behavioral data
Sofie De Cnudde, David Martens

The predictive power in ubiquitous big, behavioral data has been emphasized by previous academic research. The ultra-high dimensional and sparse characteristics, however, pose significant challenges on classification techniques. Moreover, no consensus exists regarding a feasible trade-off between classification performance and computational complexity. This work provides a contribution in this direction through a systematic benchmarking study. Forty-three fine-grained behavioral data sets are analyzed with 11 state-of-the-art classification techniques. Statistical performance comparisons enriched with learning curve analyses demonstrate two important findings. First, an inherent AUC-time trade-off is present, making the choice for an appropriate classifier depend on time restrictions and data set characteristics. Logistic regression achieves the best AUC, however in the worst amount of time. Also, L2 regularization proves better than sparse L1 regularization. An attractive trade-off is found in a similarity-based technique called PSN. Second, the results show that significant value lies in collecting and analyzing even more data, both in the instance and the feature dimension, contrasting findings on traditional data. The results of this work provide guidance to researchers and practitioners for the selection of appropriate classification techniques, sample sizes and data features, while also providing focus in scalable algorithm design in the face of large, behavioral data.

■ TD-19

Tuesday, 15:00-16:30 - 2102AB

Lot-sizing in distribution and scheduling

Stream: Lot-sizing and related topics
Invited session
Chair: Masoud Chitsaz
Chair: *Stéphane Dauzere-Peres*
Chair: *Mariá C. V. Nascimento*

1 - Logic-based Benders decomposition for capacitated lot sizing and routing problem
H. Murat Afsar, Faicel Hnaien

We propose a Logic-Based Benders Decomposition to solve a 1-level assembly lot sizing and routing problem (1-LSRP) integrating routing decisions for raw material collection. 1-level assembly lot sizing problem determines the optimal production and stocking levels under a dynamic demand to minimize total cost. The total cost is the sum of production (setup and manufacturing) and logistic (purchasing, transportation and inventory) costs. In most of the literature, the transportation is Full Truck Load and no routing decision is taken, the transportation cost is included in the purchasing cost of the item. We suppose the raw material is collected in a Less than a Truck Load manner, and routing decisions affect the transportation costs. Uncapacitated one level assembly problem with FTL policy can be solved by polynomial time algorithms but, the capacity constraint on the inventory level and LTL policy transform the 1-LSRP into a NP-Hard problem. A solution of 1-LSRP determines the production, inventory and purchasing quantities of each raw material for each time period, and as a consequence of purchasing quantities, collection routes are constructed. In many production companies, these two phases are solved consecutively yielding to a sub-optimal result. We propose a Logic-Based Benders decomposition, and solve iteratively lot sizing and routing problems. The tests indicate an improvement up to 9% compared to hierarchical approach on instances with 40 suppliers and 10 periods.

2 - A unified decomposition matheuristic for assembly, production and inventory routing
Masoud Chitsaz, Jean-François Cordeau, Raf Jans

While the joint optimization of production and outbound distribution decisions in a manufacturing context has been intensively studied in the past decade, the integration of production, inventory and inbound transportation from suppliers has received much less attention despite its practical relevance. This paper aims to fill the gap by introducing a general model for the assembly routing problem (ARP), which consists of simultaneously planning the assembly of a finished product at a plant and the routing of vehicles collecting materials from suppliers to meet the inventory requirements imposed by the production. We formulate the problem as a mixed-integer linear program and we propose a three-phase decomposition matheuristic. The algorithm is flexible and we show how it can also be used to solve two well-known problems related to the ARP: the production routing problem (PRP) and the inventory routing problem (IRP). Using the same parameter setting for all problems and instances, we obtained 818 new best known solutions out of 2,628 standard IRP and PRP test instances. In particular, on large-scale multi-vehicle instances, the new algorithm outperforms specialized state-of-the-art heuristics for these two problems.

3 - Fuzzy stochastic production-distribution problem: A modeling and solution approach
Ümit Sami Sakallı, Emre Çalışkan

Production-Distribution problem (PDP) in Supply Chain Management (SCM) is an important tactical planning operation which starts to the plan by determining raw materials that will be supplied from the suppliers and goes on making decisions related to the aggregate production planning and distribution of final products to the customers. One of the challenge on this decision is the size and complexity of supply chain system (SCS). On the other side, tactical operation is a mid-term plan for 6-12 months, therefore, it includes different type of uncertainties which is the second challenge. In the literature, the uncertain parameters were modeled as stochastic or fuzzy. However, there is a few literatures that handles stochastic and fuzzy uncertainties simultaneously in PDP. In this talk, the modeling and solution approaches of PDP which contains stochastic and fuzzy uncertainties simultaneously is handled. A solution approach that combines possibilistic programming and chance-constrained is developed for PDP. The solution approach is examined in a numerical example. The solutions of the numerical example show that the proposed modelling and solution approaches are useful to make tactical decisions for PDP.

4 - Capacitated lot sizing problem with a fixed product sequence
Xueying Shen, Stéphane Dauzere-Peres, Filippo Focacci, Fabio Furini

In this paper, we study a special case of the Capacitated Lot Sizing Problem (CLSP) with sequence dependent setups, which is called CLSP with a fixed product sequence. In some manufacturing systems, the sequence in which products are processed is fixed in order to follow certain production rules, or to minimize setup times and costs such as the ones required when changing colors. However, not all products have to be manufactured in each period. In this case, the number of potential setup sequences is reduced compared to that of the CLSP with sequence dependent setups. The problem is shown to be NP-hard, and a branch and bound algorithm is developed as well as a heuristic using column generation. A set of benchmark instances is proposed and computational results are presented to evaluate the algorithm performance.

■ TD-20

Tuesday, 15:00-16:30 - 2103

Uncertainty modeling for stochastic optimization

Stream: Stochastic optimization
Invited session
Chair: Warren Powell

1 - SDDP using a hidden semi-Markov information model
Juliana Nascimento

We propose a stochastic dual dynamic programming (SDDP) method aimed at a high-dimensional multistage stochastic optimization problem where the underlying stochastic processes are generated using a hidden two-level Markov model. This model accurately replicates both heavy tails and crossing times which reflect how long a process is above or below a forecast. Traditional SDDP works usually consider a sampled version of the true problem, assuming intertemporal independence. We do not make such assumptions. To build cuts our method dynamically samples from the full probability space and handles information processes that are state dependent (which is only partially observable), employing a Bayesian update scheme to determine the probability of being in a particular underlying state and a quadratic regularization term designed for long-horizon problems. We present computational experiments for a rich application domain, namely, optimizing energy storage and release decisions for a set of batteries scattered across the energy grid. With increased use of renewables and falling cost of storage, we anticipate having to optimize across several hundred batteries. With the fine-grained time scale of battery storage, we also have to optimize over hundreds of time periods. Our results show that even though expected costs are similar to the ones assuming intertemporal independence, we can decrease the risk when our model takes into consideration the crossing times.

2 - Bayesian optimization with gradients
Matthias Poloczek, Jian Wu, Andrew Wilson, Peter Frazier

In recent years, Bayesian optimization has proven to be exceptionally successful for global optimization of expensive multimodal objective functions. However, unlike most optimization methods, Bayesian optimization typically does not make use of derivative information. In this talk, we show how Bayesian optimization can exploit such information to greatly reduce the number of objective function evaluations required for a good performance. Our batch Bayesian optimization procedure effectively utilizes even noisy and incomplete derivative information, thereby demonstrating state-of-the-art performance compared to a wide range of optimization procedures with and without gradients.

3 - Backward approximate dynamic programming with a hidden semi-Markov information state
Joseph Durante

We consider a simple energy storage problem involving four components: a wind farm with a power output forecast, an energy storage device, a connection to the larger power grid, and a load which must be satisfied at all times. Stochastic electricity prices and wind power forecast errors are modeled using a novel hidden semi-Markov model that has relatively few information states. A key characteristic of the model is its ability to replicate the amount of time that a processes is above or below its forecast or, alternatively, a threshold level. This is an important property of stochastic processes involved in energy storage problems. Incorporating these information states into the state of the system, we then fit value functions to each system state using various backward approximate dynamic programming (backward ADP) techniques. The backward ADP methods sample states to reduce program CPU time and utilize value function forms that require little memory to store, making it possible to apply this methodology in a real world system. We compare the performance of these techniques to the optimal solution found by solving the full backward Markov decision process, as well as a simple buy low, sell high policy function approximation and a deterministic lookahead policy. We show that combining this unique type of stochastic modelling with the backward ADP approach leads to the development of more robust policies.

■ TD-21

Tuesday, 15:00-16:30 - 2104A

Agent-based simulation

Stream: Simulation
Invited session
Chair: *Patrick Hester*
Chair: *Andrew Collins*

1 - Agent-based simulation and strategic team formation
Andrew Collins, Justin E. Lane, Daniele Vernon-Bido

The modern knowledge worker is faced with managing their time across multiple projects. To ensure the successful completion of one project, the worker might be inclined to put more time into that project than was originally intended, at the expense of other projects with which they are involved. This paper looks at the impact of this type of strategic behavior on the output of research teams. Our model adapts Bakshy and Wilensky's team assembly model which investigated the formation of academic teams to complete collaborative research tasks. The agents, who represent researchers, make strategic decision to increase their prestige through the selection of the teams they work with. The results indicate that the average size of the disjoint components, sets of connected agents, decreases when prestige is introduced. This implies a smaller, more cliquey, "invisible" college is formed within a given field of study. This presentation also discusses the deeper question of including strategic group formation in agent-based simulations. Humans, unlike atoms or automaton, utilize complex psychological mechanisms to select their groups in more strategic ways than simple mathematical algorithms will allow. Policymakers could benefit from this research through the greater understanding of how humans navigate the social environment through strategic interactions.

2 - Simulation of the behavior of a set of consumers in a dynamic social network
Yony Fernando Ceballos, Daniel Anderson Soto, German Sanchez

The purchase decision of a group of people in society is mediated by the specific characteristics of the products and the communication between agents. In this research, we want to design a model to identify the relevant factors in this decision-making process. The proposed simulation use an agent based simulation approach to represent people and the decision-making process includes specific theories and tools from the psychology of consumer behavior, social networks and complex dynamical systems. The model has been developed to represent the market of mobile smartphones as a case of study.

3 - The agent-based model of coopetition on internet-based platforms
Margarita Gladkova, Nikolay Zenkevich

The market of Internet-based platforms is growing now. The platform may be considered as multi-sided market. These platforms create an environment for inter-firm relationships which can be distinguished as coopetition - a kind of interaction among organizations, which simultaneously cooperate and compete with each other (operating in one industry) to improve their financial results. Examples of such platforms are: Youtube, Uber, Amazon Marketplace. The goal of the current research is first to describe the model of coopetition among companies that operate and join Internet-based platforms. Using this model the lead generating activities on this platform are analyzed and potential impact of it is evaluated. In order to demonstrate the positive effect on some industries and the existence of some extra profitability for most companies that operate on the industry, the agent-based model was developed and simulated using tools of AnyLogic 7.3.1 software. Besides, it was shown that suggested instrument is also able to increase the degree of transparency of the market to which it is applied.

■ TD-22

Tuesday, 15:00-16:30 - 2104B

Hybrid algorithms

Stream: Constraint programming
Invited session
Chair: *Andre Augusto Cire*

1 - A decision-diagram-based approach for solving scheduling problems
Jaime E. Gonzalez, Andre Augusto Cire, Louis-Martin Rousseau, Andrea Lodi

Methods for solving optimization problems can profit by the integration of complementary strengths coming from different technologies. Multivalued decision diagrams (MDDs) present a flexible framework for modelling, capturing, and exploiting a certain problem structure. Techniques based on MDDs provide a natural way for integrating problem information coming from mixed-integer programming (MIP) technology such as bounds and additional cuts. We present a solution approach where MDDs identify parts of the search space that can be efficiently explored by MIP technology while the MIP results are iteratively used to refine the MDD representation. We discuss computational experiments on the job shop scheduling problem.

2 - A decision diagram-based Lagrangian approach to the one-to-one multi-commodity pickup and delivery traveling salesman problem
Margarita P. Castro, Andre Augusto Cire, J. Christopher Beck

We address the one-to-one multi-commodity pickup and delivery traveling salesman problem (one-to-one mPDTSP), a challenging variant of the TSP which adds the need to transport commodities between locations. Each commodity has a weight, a pickup location, and a delivery destination. The goal is to find a minimum-cost tour such that all commodities are delivered to their destination and the maximum capacity of the vehicle is not exceeded. The current literature on exact methods for the one-to-one mPDTSP typically focuses on mixed-integer programming, including Benders decomposition techniques and branch-and-cut. We propose an approach that uses a discrete relaxation based on Decision Diagrams (DDs) to better represent the combinatorial structure of the problem. We enhanced our relaxation by introducing Lagrangian multipliers, leading to significant improvements both in bound quality and run time performance. In addition, our work extends the use of DDs for solving routing problems by presenting new compilation methods and filtering rules based on capacity restrictions. Experimental results show that our approach outperforms the state-of-the-art methodologies, closing 28 open instances from the literature.

3 - Responsive mixed-initiative system for reoptimization of mixed-integer programming
Marc-André Ménard, Claude-Guy Quimper, Jonathan Gaudreault, Yassine Attik

A mixed-initiative system for interactive optimization allows a user to change the solution returned by the solver to find a more convenient solution. The user can add preferences to the solution by changing the value of the variables and the system makes sure to keep the optimality by adjusting the rest of the solution. Putting the user in the loop to find a solution helps to take into consideration unexpected events. The solution found by the solver can be optimal at first but become suboptimal or invalid when modified by a human or an adhoc solution. Changing the model and waiting the solver to solve the problem can take too much time. We designed a mixed-initiative system that helps the user to find an optimal solution in little time. The user can request to change the solution and the system proposes a new solution with three objectives in mind: to quickly provide a new solution to the system, to propose a solution as close as the user's current solution, and to provide a solution that remains optimal. The system that we introduce finds solutions before the user requests a change. When the user requests a change, the system returns a solution previously found that minimizes the number of changes to the solution. We design four methods to enumerate the possible solutions. Two methods use a linear solver, one of the methods uses a constraint programming solver with the limited discrepancy search, and the last method uses the solutions found so far to find new solutions.

4 - Dual picking for maximal reduced-cost based fixing in MIP
Louis-Martin Rousseau, Omid Sanei, Andre Augusto Cire

Reduced-cost-based filtering in constraint programming and variable fixing in integer programming are techniques which allow to cut out part of the solution space which cannot lead to an optimal solution. These techniques are, however, dependent on the dual values available at the moment of pruning. In this paper, we investigate the value of picking a set of dual values which maximizes the amount of filtering (or fixing) that is possible. We test this new variable-fixing methodology for arbitrary mixed-integer linear programming models. The resulting method can be naturally incorporated into existing solvers. Preliminary results on a large set of benchmark instances from MIPLIB suggest that the method can effectively reduce solution times on hard instances with respect to a state-of-the-art commercial solver, by a factor of almost 2x.

■ TD-23

Tuesday, 15:00-16:30 - 2105

MADM principles 3

Stream: Multiple criteria decision analysis
Invited session
Chair: Chen-Tung Chen

1 - Multi-criteria decision analysis: An evaluation model for decided of botanic drug development and its active pharmaceutical ingredient production method
Mei-Wen Wenny Kao, Po-Kun Tseng, Chin-Tsai Lin, Chyi-Jang Wu, Kai-Wun Yeh

Botanical Drug substance production method is a very important issue role as one of influence factor of drug developing success or not. This study established a multi-criteria evaluation model SSE for drug developer reference during drug manufacturing strategy decided, and SSE model was applied on CPT extraction method evaluation exercise. It results RTSES is more efficiency for Alkaloids CPT extraction than Sonication and Soxhlet method.

2 - Modeling the dynamic DEA model with measuring the carry-over effects of both human capital and organizational forgetting on the safety performance of business operations
Li-Ting Yeh

Many studies have documented that human capital continuously improves the safety performance of business operations over time. Human capital is a result of the accumulation of professional knowledge. In contrast, organizational forgetting is the loss of such professional knowledge, resulting in a lower safety performance of business operations. In this study, we attempt to incorporate both human capital and organizational forgetting into a dynamic data envelopment analysis (DEA) model that evaluates the safety performance of business operations. This requires a two-stage approach. First, we estimate the human capital and organizational forgetting for each period via regression analysis of time-series data. Second, we set these two estimated values as carry-over effects in the dynamic DEA model. This study illustrates our methodology, which involves using an empirical application to evaluate the safety performance of 11 industries in Taiwan.

3 - A fuzzy cognitive map model with linguistic decision information
Chen-Tung Chen, Wei-Zhan Hung, Hui-Ling Cheng, Jheng-Han Sie

In general, many factors and the causal relationships of factors should be considered in a system. Simultaneously, the influenced factors are always interacted with each other and will impact on system performance directly or indirectly. Fuzzy cognitive map (FCM) is one of analysis tools that it illustrates the causal relationship of influence factors by the network structure. It is often need to aggregate the opinions of experts in the construction process of fuzzy cognitive map. However, the opinions of experts will involve the uncertainties and fuzziness because the qualitative factors and subjective judgment of experts. It is reasonable for experts to use the linguistic variables to express their opinions in the construction process of fuzzy cognitive map. Most of the studies with fuzzy cognitive map did not discuss the method for aggregating the linguistic opinions of experts to reach the consensus. It will reduce the effectiveness of the fuzzy cognitive map. Therefore, this paper will present a method based on the computation of linguistic variables to transform and aggregate the linguistic information of experts. Based on the distance measurement function, this paper will present an effective approach to adjustment the opinion and consider the importance degree of each expert to reach the group consensus. And then, a linguistic decision-making analysis model will be presented in this paper based on the fuzzy cognitive network structures.

■ TD-24

Tuesday, 15:00-16:30 - 301A

Innovations and analysis of EMS in Nova Scotia

Stream: CORS SIG on healthcare
Invited session
Chair: Peter Vanberkel

1 - An empirical analysis and simulation model of ambulance offload delay
Molly Elliott, Peter Vanberkel, Alix Carter

When an ambulance delivers patients to the emergency department (ED), "offload delay" frequently occurs due to ED congestion. Offload delay results in the ambulance having to wait with the patient instead of returning to service. A possible solution to this problem is the Offload Zone (OZ)—an intermediary area where patients can be monitored while awaiting ED admission. OZs have not resulted in the expected improvements, and redesigning them is the focus of this research project. Previous research on the OZ has included process-mapping to identify possible problem areas and developing a mathematical model to compare scenarios with and without an OZ. To validate and build on previous research, empirical analyses and simulation modeling are being undertaken. Data on time stamps, triage levels, demographics, and OZ usage were obtained from hospital and ambulance information systems. Empirical analyses show the effects the OZ has on offload delay and under what circumstances it results in reduced offload delay. The simulation examines the effects of suggested changes to the OZ, to validate the previous mathematical model of the OZ, and to generate hypotheses for follow-up research.

2 - An empirical analysis of the effect of ambulance offload delay on the efficiency of the ambulance system
Mengyu Li, Peter Vanberkel, Alix Carter

When emergency departments (EDs) are congested and cannot accept incoming ambulance patients immediately, a common action is to let paramedics continue to provide patient care until an ED bed becomes available. This delay in transferring a patient from the ambulance to the ED is referred to as ambulance offload delay (AOD). AOD is a growing problem in Canada as the time to transfer an ambulance patient to an ED can be significant. This can negatively affect the ability of the ambulance service to respond to future calls and reduces the efficiency of the system. Using data from a partnering hospital and partnering EMS provider, the efficiency and effectiveness of the EMS system is determined for a range of AOD scenarios.

3 - Mixing scheduled patients with walk-in patients at collaborative emergency centres
Jacob Wing, Peter Vanberkel, Alix Carter

The Collaborative Emergency Centre (CEC) care model was initiated by the Nova Scotia Department of Health and Wellness in 2010. The CEC model of care appears to be a promising way to reorganize and improve emergency care for rural Nova Scotians. Several challenges related to their operations remain. A concern identified by a focus group reviewing CECs, stated that the daytime CEC physicians did not want to book a full day of appointments because of the unpredictability of the numbers of walk-in (or CEC return) patients. Likewise, same-day / next day appointments were not always available for CEC return patients. An appointment scheduling system is being developed that considers the environmental factors unique to CECs and incorporates patient type specific appointment durations. The optimal placement of appointments of varying lengths will be determined as well as when throughout the day capacity should be reserved for unscheduled walk-in patients.

4 - A geospatial analysis of the Nova Scotia emergency care network
Lauren McNamara, Peter Vanberkel, Alix Carter, David Petrie, Samuel Campbell

The objective of this study is to measure how the Nova Scotian Emergency Medical System (EMS), consisting of Emergency Departments (EDs) and ambulance services, covers the population, and provide a tool to evaluate changes to the system. This study uses location-allocation models including the P-median problem (PMP), P-centre problem (PCP), maximal covering location problem (MCLP), and the location set covering problem (LSCP). Distance is measured in kilometres following the road network, and NS is divided into a grid where each square has a population and the potential to house a facility. We analyze the existing network by computing the weighted travel distance of the population to each facility, the maximum distance any person must travel, and the number of people within a specified distance from a facility. We also consider several proposed changes to the network and compute the degree of improvement expected using these metrics.

■ TD-25

Tuesday, 15:00-16:30 - 301B

Game theory and optimization for health and life sciences 1

Stream: Optimization, analytics and game theory for health and life sciences
Invited session
Chair: *Elena Gubar*
Chair: *Gerhard-Wilhelm Weber*
Chair: *Ryan Palmer*

1 - Comparison of static ambulance location models
Theresia van Essen, Pieter van den Berg

Over the years, several ambulance location models have been discussed in the literature. Most of these models have been further developed to take more complicated situations into account. However, the existing standard models that are often used in case studies have never been compared computationally according to the criteria used in practice. In this presentation, we compare several ambulance location models on coverage and response time criteria. In addition to four standard ambulance location models from the literature, we also present two models that focus on average and expected response times. The computational results show that the Maximum Expected Covering Location Problem (MEXCLP) and the Expected Response Time Model (ERTM) perform the best over all considered criteria. However, as the computation times for ERTM are long, the Average Response Time Model (ARTM) could be a good alternative. Based on these results, we also propose four alternative models that combine the good coverage provided by MEXCLP and the quick response times provided by ARTM. All four considered models provide balanced solutions in terms of coverage and response times. However, the Multiple Response Times Target Model (MRTTM) outperforms the other models based on computation time.

2 - Appointment scheduling of MRI examinations
Bjørn Nygreen, Anders N. Gullhav, Marielle Christiansen, Hanna Selvaag, Anders Eilertsen

With the increasing demand for magnetic resonance image (MRI) examinations, the manual scheduling of patients at hospital MRI labs becomes unmanageable without decision support tools. We study the appointment scheduling problem at MRI labs, with the objective of supporting the planners. In this problem, both inpatients and outpatients are to be allocated to a time and date at one out of several MRI labs. The patients have different urgency levels, and require MRI examinations of various lengths. An important consideration is to ensure that there is enough available time slots for urgent patients. If there are too few time slots for urgent patients, delays and rescheduling will occur. On the contrary, too many time slots reserved for urgent patients will lead to inferior utilization. In our study, the appointment process is simulated, and different scheduling approaches are analyzed by using real world data obtained from a Norwegian hospital.

3 - Fokker-Planck equation and protein folding problem
Elso Drigo Filho, Franciele Polotto, Jorge Chahine, Ronaldo J. Oliveira

The Fokker-Planck equation with a bistable potential is used to analyze the process of protein folding. The problem is not exactly solvable and the proposed approach is based on an analysis of the Schrödinger equation through the variational method. The kinetics of the time-dependent probability distributions over thermodynamic free energy profiles of the protein folding are compared with the computational simulation results. The system used to compare the results is a protein of the hyperthermophilic bacterium Thermotoga maritima (TmCsp).

4 - Evaluating community healthcare by incorporating care outcomes into patient flow modelling
Ryan Palmer, Martin Utley

In recent decades, an ambition of UK healthcare policy has been to deliver more care in the community by moving services from acute settings closer to patient homes. However, questions remain over the impact of shifting these services. This is complicated by a lack of comparable measures, nationally and locally, for evaluating quality across differing community services. In this project we aim to aid the evaluation of community services by developing a novel patient flow model which incorporates patient outcomes. The model includes dynamics of patient flow common to community care such as the use of multiple services and possible re-use of services. Furthermore we represent outcomes as states which patients may move between during a course of care. These outcome states are thus used to model differentiated service and measure performance. To this end, we extend a first order fluid approximation of a stochastic queueing system with service reuse to include these dynamics. In considering differentiated service we implement a novel method for dynamically allocating servers across parallel queues and outcome states to overcome problems of server inactivity. Furthermore, we develop the concept of "the flow of outcomes" - how individual services contribute to the output of outcomes from a system of care over time - to provide insight and understanding into the performance of interrelated healthcare services.

■ TD-26

Tuesday, 15:00-16:30 - 302A

Equilibrium problems in energy 1

Stream: Equilibrium problems in energy
Invited session
Chair: *Afzal Siddiqui*
Chair: *Steven Gabriel*

1 - Power and heat market model: Cross-commodity effects in the Nordic energy system

Ahti Salo, Vilma Virasjoki, Afzal Siddiqui, Behnam Zakeri

Power markets are changing in that the share of energy efficient production and variable renewable energy (VRE) is increasing while energy systems are becoming more interconnected. These trends have implications for the need and role of energy efficient combined heat and power (CHP) plants. In fact, CHP plants in deregulated power markets have an asymmetrical link to the regulated district heating (DH) sector in which production and price are fixed rather than driven by the markets. Combining this with the possibility that producers exert market power by seeking to impact power prices, it is important to understand the dynamics of the coupled energy system. We therefore study whether CHP's link to regulated markets mitigates market power, and whether market power can be reflected in DH supply. We use complementarity modelling and give a numerical example for the Nordic system. Specifically, we model the power network as a mix of direct current (DC) lines and DC load flow linearized alternating current (AC) lines, formulate perfect competition (PC) and Cournot oligopoly (CO) models, and solve the market equilibrium with GAMS. The results show that the possibility to exert market power in electricity markets impacts the DH sector, too. Furthermore, CHP's link to regulated DH affects the ability of CO producers to increase power prices. The insights from these results help formulate clean energy policies while aiming to uncover and reduce the impacts of using market power.

2 - Evaluating an interconnection project: Do strategic interactions matter?

Sébastien Debia, David Benatia, Pierre-Olivier Pineau

High-Voltage Direct Current (HVDC) merchant transmission lines allows trade across separate power markets and often in different countries. The flows on existing cross-border lines are often assessed as suboptimal, which may be due to the light regulation that often prevails in this case. We study the impact of Physical Transmission Rights (PTRs) allocation on the management of an HVDC interconnection between a thermal and a hydroelectricity market, assuming dynamic water management. We use a two-stage game formulated as an Equilibrium Problem with Equilibrium Constraints (EPEC) to model the strategic trade between the New York (US) and Quebec (Canada) systems. The numerical model is calibrated with public data. We find that although the interconnection can create wealth, a high concentration of PTRs can destroy value because of dumping strategies. The impact of trade on local price levels may be of concern and calls for the functional unbundling of traders and generators.

3 - A simulation-based model for optimal demand response load-shifting: Case study for the Texas power market

Steven Gabriel

This paper describes a prototype Monte Carlo simulation tool, used to evaluate retail demand response programs for the Texas power market (ERCOT) but is also applicable to many other regions. The model simulates a type of demand response called load shifting, a direct load-control technique where customers' power consumption is adjusted during certain time periods, called DR events. This study identified an optimal load control schedule based on forecasted load, settlement point prices, and weather variables but taking into account stochastic load and prices as well as grey-box thermodynamic modeling. An optimal schedule is defined as the schedule that maximizes the retail electric power provider's profit and minimizes risk of low profits. The DR program controls customers' load with smart thermostats using the Connected Savings application from Earth Networks.

4 - Sustainable transmission planning in imperfectly competitive electricity industries: Balancing economic efficiency and environmental outcomes

Afzal Siddiqui, Makoto Tanaka, Yihsu Chen

We address the problem of a TSO that builds a transmission line in order to maximise social welfare inclusive of the cost of emissions. A TSO in a deregulated industry can only indirectly influence outcomes via its choice of the transmission line capacity. Via a bi-level model, we show that this results in less transmission capacity with limited emissions control if industry is perfectly competitive. A carbon tax on industry leads to perfect alignment of incentives and maximised social welfare only under perfect competition. By contrast, a carbon tax actually lowers social welfare under a Cournot oligopoly as the resulting reduction in consumption facilitates the further exercise of market power.

■ TD-27

Tuesday, 15:00-16:30 - 302B

Theoretical issues in behavioural OR

Stream: Behavioural OR
Invited session
Chair: *Leroy White*

1 - Behavioural system dynamics: A first sketch map of the territory

David Lane

With the 'behavioural turn' in full sway across OR, we consider its application to System Dynamics. Interest then falls on complex dynamic systems, how they perform over time and whether empirical accounts of what humans do when dealing with such systems reveal departures from normative rationality. A 'Behavioural SD' approach promises much. Within the field there is already a considerable amount of empirical evidence regarding human inability to understand stock/flow relationships and difficulties in extrapolating exponential trajectories, along with a long-standing interest in deficiencies in mental models and their consequences for system performance. However, the 'territory' is potentially much greater than this, involving a network of areas, from human response to and understanding of actual systems of this type, to the use of maps and models to learn about them, the difficulties in creating such models, how one represent 'behavioural effects' within models and the problem of getting individual or groups to learn from such models. The sketch of the territory therefore reveals much scope for the application of a behaviouralist view to SD. However, the paper also tries to consider whether 'Behavioural SD' is merely a vast conceptual blanket, little more than an exercise in changing the labels on established areas of interest, or whether it provides a conceptual lens that can generate important new insights.

2 - The role of artefacts within facilitated modelling workshops
Thanos Papadopoulos, Elena Tavella

Scholars have emphasized the role of artefacts and conversational practices within Facilitated Modelling (FM) workshops. However, there is a dearth of research into how artefacts and discursive practices are intertwined at the micro-level of such workshops. To address this gap, we apply Adaptive Structuration Theory in an analysis of an FM workshop with top managers. We contribute to behavioral OR practice by arguing that the appropriation of artefacts by top managers enables them to engage in negotiations of meaning with action implications effectively, but appropriation occurs at varying intensities depending on the issue of concern. Moreover, we identify that artefacts are reproduced if their reproduction is an aim or part of an aim of strategic discourse.

3 - Theorising collective behaviour in OR interventions with Searle's social ontology
Katharina Burger, Leroy White

To understand the efficacy of OR processes, it is necessary to theorise in order to explain collective cognitive and behavioural processes in OR interventions. We propose an action-oriented interpretation of Searle's social ontology as a process-based view of the collective construction of social reality in OR practice. By conceptualising Collective Intentionality as at once situated and yet irreducible to the individual mind, this may provide an alternative perspective on the complex fabric that makes up problem structuring processes. We argue that Searle's social ontology serves both pragmatic as well as theoretical purposes in disambiguating the processes involved problem structuring interventions.

4 - Social embeddedness, behavioural OR and group decision support: What is the connection?
Leroy White

Researchers have long argued that little attention is paid to the social processes (and outcomes) in the use of Group Decision Support (GDS) processes with senior managers. This paper is concerned with the social process demands in the use of GDS and is focused on the role of the social relationships of managers within a GDS context. The paper will draw on the effects of social networks on managers' effectiveness and behaviour and extend the discussion to GDS interventions. In particular, the paper will look at how things flow in terms of social embeddedness (i.e. individuals continuously combine and modify their views through interactions with each other). As well as this, the paper considers the question of how to transform knowledge into action that resides in social relations.

■ TD-28

Tuesday, 15:00-16:30 - 303A

Computational biology, bioinformatics and medicine

Stream: Computational biology, bioinformatics and medicine
Invited session
Chair: *Jens Allmer*
Chair: *Gerhard-Wilhelm Weber*
Chair: *Jacek Blazewicz*

1 - Heuristics for rank aggregation in evolutionary microbiology
Alexander Bolshoy

Since 1995, genomics has dramatically changed. Today, it is possible to completely sequence a bacterial genome in a few hours. Sequencing of bacterial genome sequences is now a standard procedure, and tens of thousands of bacterial genomes are available today. Major part of the prokaryotic proteins can be gathered in Clusters of Orthologous Groups (COGs). So, many studies are performed on COGs ignoring "non-having homologs proteins". Each protein-coding gene in a given genome has several attributes in addition to belonging to a certain COG: gene length, number of gene copies in a given genome, GC-content, etc. About 1,500 prokaryotic genomes are COG-annotated and, potentially all those tens of thousands of genomes can be easily COG-annotated as well. Genomes can be partially ranked by each COG and every attribute; however, these rankings would be rather different. Many ranking methods are ill-suited for this case because COG lists are inherently noisy and database is rather biased. Among ranking methods that can be applied, probably, the best approach is Kemeny aggregation criterion. This approach has a rich history in the fields of information retrieval, theory of social choice, etc. However, finding the best ranking is often computationally very expensive, and, thus, different heuristics must be applied. In our study, we present results of application different heuristics to ranking of 1500 prokaryotic genomes according to: gene lengths and number of gene copies.

2 - Structural alignment of contact-based 3D protein substructures: The problem and its implementation on Optil.io platform
Maciej Antczak, Marta Kasprzak, Piotr Lukasiak, Szymon Wasik, Jacek Blazewicz

A spatial neighborhood of a residue, known as a structural descriptor, is represented by a set of discontinuous fragments of a molecule chain closely located in three dimensions, however, not necessarily close along the sequence. The concept of local descriptors was proposed to reliably analyze sequence-structure relationships in non-homological proteins. Several applications of this concept proved its usefulness for insight into protein structures, e.g., residue-residue contact prediction, structural alignment of protein structures. The application of a reliable and efficient algorithm for structural alignment of descriptors determines the success of this approach. Here, we present a novel combinatorial model based on the maximum-size assignment problem and polynomial-time algorithms that ensure high-quality results regarding accuracy, as well as processing efficiency. The algorithms can be simply applied, e.g., to reveal recurring local substructures within RNA-protein complexes or analyze sequence-structure relationships in helices of transmembrane proteins. Currently, we introduce this problem at the Optil.io platform, which is an online judge system designed for continuous evaluation of solutions of optimization problems. Our aim is to verify the quality of our algorithms in comparison with other solutions proposed by Optil.io users. To widen the interest among participants without the biological background, we simplified the description of this problem there.

3 - Stochastic optimal control of impulsive systems under regime switches and paradigm shifts, in biology, finance and economics
Gerhard-Wilhelm Weber, Emel Savku, Azar Karimov, Nadi Serhan Aydin

We contribute to modern Operational Research by hybrid, e.g., mixed continuous-discrete dynamics of stochastic differential equations with jumps and to its optimal control. These hybrid systems allow for the representation of random regime switches or paradigm shifts, and are of growing importance in science, especially, biology, in economics, finance and engineering. We introduce some new approaches to this area of stochastic optimal control and present results. One is analytical and bases on the finding of optimality conditions and, in certain cases, closed-form solutions. We further discuss aspects of differences in information, given by delay or insider information. The presentation ends with a conclusion and an outlook to future studies.

■ TD-29

Tuesday, 15:00-16:30 - 303B

Optimization in unconventional oil and gas resources development

Stream: OR in the oil and gas sectors
Invited session
Chair: Zukui Li

1 - Stochastic programming models for optimal shale well development and refracturing planning under exogenous and endogenous uncertainties
Ignacio Grossmann, Markus Drouven, Diego Cafaro

In this work we present a comprehensive optimization framework to address the shale gas well development and refracturing planning problem. At its core, this problem is concerned with if and when a new shale gas well should be drilled at a prospective location, and whether or not it should be refractured eventually over its lifespan. Within the optimization framework, we account for two major sources of uncertainty: exogenous gas price uncertainty and endogenous well performance uncertainty. We propose a mixed-integer linear, two-stage stochastic programming model embedded in a moving horizon strategy to dynamically solve the practical planning problem under exogenous and endogenous uncertainty. The framework is based on a novel, generalized production estimate function that predicts the gas production over time depending on how often a well has been refractured and when exactly the well was restimulated last. Based on a detailed case study we conclude that early in the life of a shale well, refracturing makes economic sense even in low-price environments, whereas additional restimulations are only justified if prices are elevated.

2 - Projection-based reformulation and decomposition algorithm for mixed-integer bilevel linear programs and application on noncooperative shale gas supply chain
Fengqi You

Mixed-Integer Bilevel Linear Program (MIBLP) is a class of most challenging optimization problems that has a bilevel optimization structure and includes integer variables in both upper and lower problems. Existing MIBLP algorithms are either subject to simplifying assumptions on the integrity of parameters/variables or restrictions on the presence of upper-level connecting constraints. The complexity of bilevel optimization lies in the property that constraint region of the upper-level problem is partially determined by the solutions to a lower-level optimization problem. MIBLP problems are further complicated because 1) the bilevel feasible region can be nonconvex and disconnected; 2) removing the integrality constraints does not necessarily provide a valid relaxation of the original MIBLP problem; 3) lower-level optimal solutions are not always feasible to the original MIBLP when upper-level connecting constraints are present. In this talk, I will present recent theoretical, algorithmic and computational results on global optimization of large-scale MIBLPs. After discussing theory and proprieties of MIBLPs, I'll introduce a novel MIBLP algorithm that has the least restrictions on problem structure and outperforms existing ones by at least several orders of magnitude in terms of computational efficiency. An application to noncooperative shale gas supply chain optimization will be presented to illustrate the applicability and efficiency of the proposed algorithm.

3 - Strategic optimization of the oil sands SAGD drainage area arrangement and development planning
Zukui Li

The majority of the oil sand deposits in Alberta Canada can only be extracted using in situ methods, mainly the Steam Assisted Gravity Drainage (SAGD). A SAGD project normally targets the development of a number of drainage areas consisting of multiple injector and producer well pairs situated subsurface. Drainage area placement and development planning is crucial in a SAGD project. In this talk, an optimization framework for planning the development of SAGD drainage areas is discussed. The proposed framework includes the following major elements. First, an algorithm for compact drainage areas arrangement towards maximizing the amount of extractable bitumen is discussed. Second, a mixed integer optimization model is developed to arrange the multiperiod development plan of the drainage areas with consideration of capital and steam allocation restrictions. Third, uncertainties in crude oil price and reservoir property are investigated based on the deterministic optimization model. The proposed method is applied to a case study with multiple drainage areas. The results demonstrate that the method can effectively generate a good drainage area layout and an economically optimal development plan that maximizes the net present value.

4 - Stochastic programming approach to integrated shale gas supply chain design and water management
Omar Guerra, Gintaras V. Reklaitis

Shale gas production is expected to rise by almost two-fold from 2013-2040. However, the exploitation of shale gas plays requires consideration of important environmental challenges and risks associated with water management. Thus, beside the design and planning of gas production, transportation, and processing network, the design and implementation of effective water management strategies for shale gas operations is needed. Moreover, shale gas and water supply chain design is subject to uncertainties regarding the productivity of the shale play, wastewater composition, gas spot prices, etc. This study presents an overview of natural gas market, in which potential shale gas developments and water management issues around the world are identified. Additionally, a two-stage stochastic model in developed and implemented for the design and planning of integrated water and shale gas supply chains. First, the effects of uncertainties on the economics of shale gas development are quantified and discriminated using a global sensitivity analysis. The Sobol's sequence sampling approach is used to estimate Sobol's sensitivity indices. Then, a two-stage stochastic model is developed and formulated in a deterministic form as a mixed integer linear program with appropriate scenarios. The benefits of modeling the uncertainty and implementing the stochastic approach are evaluated via two metrics: expected value of perfect information (EVP) and value of stochastic solution (VSS).

■ TD-30

Tuesday, 15:00-16:30 - 304A

Uncertainties in biomass-based supply chains

Stream: Biomass-based supply chains
Invited session
Chair: Sandra Eksioglu

1 - Cloud-based decision support system integrating biomass quality and uncertainty to optimize the production of biofuels
Krystel Castillo, Mario Aboytes-Ojeda, Sandra Eksioglu, Mohammad Roni

In recent years, the bioenergy industry has seen the advent of highly complex, large-scale logistics systems. This presentation focuses on a unified computational and theoretical scheme to integrate quality/technology/supply uncertainties in supply chain decision making process via the use of stochastic programming and the development of efficient solution procedures to solve large-scale problems in order to decrease the losses that many bioenergy industries currently face and to identify a standardized biomass conversion technology. We present an integrated model for computing the cost incurred within a supply chain due to the biomass quality (defined as moisture, ash, and sugar contents, among others) and supply variability. Specifically, we developed a two-stage stochastic hub-and-spoke supply chain model that considers the biomass quality variations. We also present efficient algorithms to find a logistics design which is robust to fluctuations of biomass quality and supply. A case study in the South Central Region of the United States is used to illustrate the performance of the model and algorithms. Scenarios based on varying weather conditions are created using realistic data from this region and results are discussed. Moreover, we will present our progress made towards an integrated decision support system (DSS) that holistically optimizes decisions to facilitate the dissemination of the integrated models developed.

2 - Stochastic models for an optimal blending of biomass under cost, quality and uncertainty considerations
Mowen Lu, Sandra Eksioglu

Blending biomass materials of different physical or chemical properties provides an opportunity to passively adjust the quality of the feedstock to meet the specifications of the conversion platform. However, blending decisions must deal with the stochastic nature of biomass availability and quality. To address this problem, we propose a chance-constraint programming (CCP) model which models theses uncertainties in a thermochemical conversion process. The proposed model considers uncertainties in the (1) physical/chemical characteristics of biomass; and (2) supply availability of each feedstock. The proposed CCP model identifies the right mix of biomass to optimize the performance of the thermochemical conversion process at the minimum cost. We employ the sample average approximation (SAA) approach to solve this problem. We evaluate the performance of the proposed model via a case study focused in South Carolina. We develop the case study using data provided by the Billion Ton Study. We conduct a sensitivity analysis to evaluate the impact of biomass quality and availability on the solutions obtained by SAA. The results indicate that variations of ash content have a greater impact on the expected total cost than variations in biomass supply and heating values. Our numerical analysis indicates that solutions obtained via SAA generate true lower bounds to the original problem for a given confidence level.

■ TD-31

Tuesday, 15:00-16:30 - 304B

Teaching OR/MS 3

Stream: Teaching OR
Invited session
Chair: *José L. Pino*
Chair: *Yaroslavna Pankratova*

1 - Master's degree program on game theory and operations research
Yaroslavna Pankratova, Elena Gubar, Leon Petrosyan, Vladislav Taynitskiy, Natalia Vasilyeva

The two-year master's degree program in Game Theory and Operations Research prepares a student for a career in industry, science and education. The program facilitates learning in modern concepts, techniques and methods in the game theory and leads the student to different functional areas of operations research. The courses are designed to study theory and methods of operations research, game theory, econometrics, applied statistics, decision theory, queuing systems, applications of computer technologies in operations research. The students are involved in research projects connected also with computer science, inventory and project management, joint venture, network modeling, propagation and epidemic models, bioinformatics and related topics. For the first two terms, the core courses will focus on the fundamentals of game theory, operations research, statistics and econometrics —taught from a global perspective. The second year students will then tailor the final special courses to your individual interests and career goals with the final project which will be presented at the end of the program as master dissertation.. The publication of results in scientific journals and presentations on international OR and Game Theory conferences are highly welcomed.

2 - Affecting performance in tertiary education by means of mathematical modeling
Hennie Kruger, Tiny Du Toit, Annette van der Merwe

It has been determined that students are inherently motivated to improve and work harder when they are periodically informed on their academic progress. Recently, a novel academic ranking system has been implemented in an IT-module. In addition to periodically informing the students on their progress, this system calculates levels of participation empirically. In this study, a non-linear programming model was created to find the best equation that calculates the extent of student participation. The model was able to reduce the execution time of the ranking system. In order to encourage a self-regulatory attitude among the students, a data envelopment analysis (DEA) based only on outputs was performed to sort the students into levels of output efficiency. The lecturer can determine intermediate improvement targets for each of the factors used for the levels of the ranking by considering the dual-formulation of the DEA model. Results obtained by the study was confirmed by a student survey. This survey showed that when the students are aware of their ranking relative to their peers, most of them felt motivated to improve their academic performance.

3 - Using SPC techniques to monitor students' evaluation of university courses and faculty members' teaching performance
Sofia Sivena, Yiannis Nikolaidis

SQC and control charts have been broadly used in manufacturing companies for monitoring quality of products. Since the late 1980s, though, their use has also expanded in the service sector. Higher education belongs to the service sector as it presents some of its typical characteristics. Quality control of its operations is absolutely necessary; students, as main beneficiaries, demand the evaluation and the continuous improvement of their professors' teaching performance as well as of the learning process of their courses. In Greece, a type of faculty members' evaluation is realized by students and a common tool used for this purpose is the survey questionnaire that students fill out each semester. The use of control charts which we propose for data (collected through the aforementioned questionnaire) monitoring and analysis will help any educational institute to comprehend the reasons that may hinder the successful teaching process and to adopt policies that will improve it. To choose the proper type of control charts, we consider that a traditional measure of their performance is their ARL. We compare the performance of several types of control charts as per the ARL when the teaching process is either in control (i.e. ARL0) or out of control (i.e. ARL1). To this purpose, we use Monte Carlo simulation. Creating simulation samples is based on various empirical and theoretical distributions. The first results of our numerical investigation are to be presented.

4 - OR/MS in executive masters in higher education management
José L. Pino, M' Teresa Cáceres

The managers of Higher Education Institutions need to have competencies in areas such as leadership, governance, accreditation, institutional research, international cooperation, finance, facilities, fundraising, human resources, student life, recruitment and retention. In many countries it is not necessary to have specific formation to be members of Higher Education Institution director's board. One of the options for improving the competencies of directors of these institutions are Executive Masters designed for managers or executives with several years of work experience. These programs allow directors to further develop their skills, while largely maintaining their day-to-day work schedule. As in the MBA, the core subjects in these programs are Analytical (accounting, economics, operations research, and quantitative analysis), Functional (financial management, human resource management, and operations management) and Ethics Social responsibility, corporate governance). In all learner oriented curriculum design must be considered the heterogeneity of students, but this is a crucial aspect in disciplines as MS / OR, that deals with the application of advanced analytical methods to help make better decisions. The objective of this paper is to show the themes of MS / OR that has been included in International Executive Masters in Management of Higher Education

Institutions in Spain, Colombia, Dominican Republic within the AUIP network of universities.

Tuesday, 16:45-18:15

■ TE-01

Tuesday, 16:45-18:15 - 307B

Risk analysis and management

Stream: Decision making modeling and risk assessment in the financial sector
Invited session
Chair: *Gerhard-Wilhelm Weber*
Chair: *Katsunori Ano*
Chair: *James Liou*

1 - Longevity risk management for annuities by longevity derivatives
Tadashi Uratani

Under growing market of mortality derivatives, we consider risk management for longevity risk of annuities using longevity derivatives. Assuming stochastic interest rate and mortality process, we derive hedging portfolio strategies for annuities by using the criterion of risk-minimization by Foellmer. We compare the effectiveness of longevity derivatives.

2 - Hedging rainfall risk with derivatives in hospitality industry
Cristian Pelizzari, Simona Franzoni

Hospitality firms have little opportunities to influence the phenomenon of heavy rain. In fact, rainfall risk, as a factor external to the firm, is difficult to predict, to manage, and to monitor, therefore hospitality industry should take appropriate decisions to hedge such a risk. The present work contributes to the tourism and weather literature by advancing a scientific framework for rainfall risk management of hospitality firms. Firstly, we focus on the assessment of the correlation between business performances and rain. Secondly, we propose a financial instrument able to hedge rainfall risk, i.e. to mitigate the negative impacts of rain on the business performances of hospitality firms. The proposed model borrows its foundations from the Enterprise Risk Management (ERM) by the Committee of Sponsoring Organizations of the Treadway Commission (COSO). The model is supported by a numerical application based on the main profitability ratios of 18 hotels located on Lake Garda (Italy) in the decade 2005-2014 and on the amounts of rain fell on that lake in that decade. The empirical analysis demonstrates, by means of scenarios, that there is a correlation over time between business performances and rain. A rainfall derivative is introduced and priced through Monte Carlo methods based on copulas. The risk of such a derivative is assessed.

3 - A note on real estate pricing models with exogenous variables
Hiroshi Ishijima, Akira Maeda

We develop a pricing model of real estate that incorporates conventional hedonic attribute variables of real estate as well as exogenous variables, namely financial asset prices; this model is based on a theoretical pricing model that we, fundamentally develop. Specifically, our model features a pricing kernel expressed as the product of a cash-flow pricing kernel (stochastic discount factor) and a hedonic pricing kernel. Furthermore, we conduct an empirical analysis to understand Japanese real estate prices comprehensively. Our analysis reveals that the financial asset prices and conventional hedonic variables serve as the major determinants of Japanese real estate prices.

4 - A novel MCDM based FMEA model for risk analysis
James Liou, Huai-Wei Lo

Failure mode and effect analysis (FMEA) is a forward-looking risk management techniques used in various industries for promoting the safety and reliability of systems, products, processes, structures and services. However, FMEA has many defects in practical experiment. Therefore, this paper proposes a new model that uses a multi-criteria decision-making method (MCDM) based FMEA model. This approach has several advantages: (i) it adds the prevention cost in the original risk priority number (RPN) to reflect actual resource limit; (ii) it considers the different weights of severity, occurrence, detectability and cost based on the best-worst method in RPN calculation; (iii) it uses interval a linguistic variable to cope with information uncertainty; (iv) it applies a probability based grey relational analysis to calculate RPN. To illustrate the applicability of proposed model, a real data from electronic company was applied to demonstrate its usefulness and effectiveness. The proposed model can provide a risk priority solution of the product development.

■ TE-02

Tuesday, 16:45-18:15 - 308B

Metaheuristics for combinatorial optimization problems

Stream: Metaheuristics - Matheuristics

Invited session

Chair: Francis Vasko

1 - Binarizations of continuous metaheuristics to solve the set covering problem: Simpler is better

Francis Vasko, Yun Lu

Recently, a number of metaheuristics originally designed for solving continuous nonlinear optimization problems have been adapted to solve the Set Covering Problem (SCP) which is a well-known discrete optimization problem. Many of these metaheuristics are bio-inspired and include Bee Colony, Black-Hole, Cat Swarm Optimization, Cuckoo Search, Electromagnetism-Like, Firefly Optimization, and Teaching-Learning Based Optimization (TLBO) algorithms. In this talk we will review how these metaheuristics are adapted or "binarized" to solve the SCP. Also, we will discuss how another metaheuristic, JAYA, just introduced in 2016 for solving continuous nonlinear optimization problems can be easily adapted to solve the SCP. The performance of all these metaheuristics on the SCP will be evaluated based on how well they solve 65 SCPs from Beasley's OR library. The empirical results demonstrate that the simple, straightforward binarization approach used by Lu and Vasko on the TLBO metaheuristic gives the best results.

2 - Population-based metaheuristics for the multiple-choice multidimensional knapsack problem

Yun Lu, Francis Vasko

In this paper, we study the performance of five population-based metaheuristics to solve a large (393) number of comprehensive problem instances from the literature for the important (NP-Hard) multiple-choice multidimensional knapsack problem (MMKP). The five metaheuristics are: teaching-learning-based optimization (TLBO), artificial bee colony (ABC), genetic algorithm (GA), crisscross optimization algorithm (COA), and binary bat algorithm (BBA). All five of these metaheuristics are similar in that they transform a population of solutions in an effort to improve the solutions in the population and they are all implemented in a straightforward manner. Statistically (over all 393 problem instances), we show that COA, GA and TLBO give similar results which are better than other published solution approaches for the MMKP. However, if we incorporate a simple neighborhood search into each of these five metaheuristics, in addition to improved solution quality, there is now no statistically significant difference among the results for these five metaheuristics.

3 - Adaptation of firefly algorithm to solve GAP

Gilberto Torres-Cockrell, Javier Ramirez-Rodriguez, Roman Anselmo Mora-Gutiérrez, Eric Alfredo Rincón-García, Antonin Ponsich

In this work, trhee adaptation of the Firefly Algorithm (FA) to solve General Assignment Problem (GAP) are presented. Those adaptations involve a discretization of the original FA, also, two purpose method are hybrid metaheuristic between FA and local search. Whit aim characterizes the behaviour of our methods, Those uses to solve 15 benchmark instances of the GAP, which were taken from OR-Library and they are kind "C, D, E". Numerical results show that the methods developed are able generate good results.

4 - PSO-3P for portfolio optimization problem

Javier Ramirez, Sergio de-los-Cobos-Silva, Miguel Angel Gutierrez, Pedro Lara-Velazquez, Roman A. Mora Gutiérrez, Antonin Ponsich, Eric Alfredo Rincón-García

The constrained portfolio optimization problem with multi-objective functions cannot be efficiently solved using exact techniques. Thus, heuristics approaches seem to be the best option to find high quality solutions in a limited amount of time. For solving this problem, we propose a new variant of Particle Swarm Optimization named PSO-3P. PSO-3P incorporates two strategies of diversification and intensification to improve the performance of the classical PSO algorithm. The proposed algorithm was tested over five well-known benchmark data sets and the obtained results prove to be highly competitive since they outperform those reported in the specialized literature in almost all tackled instances.

■ TE-04

Tuesday, 16:45-18:15 - 202

Location, logistics, transportation and traffic 4

Stream: Location, logistics, transportation, traffic (contributed)

Contributed session

Chair: Alexander Belenky

1 - Real-time book collection location search system

Tomoki Hirai, Hiroyuki Ebara

The book is very important in learning and studying. There are many books in a library, office and laboratory. However, we hard to find needed books. In this study, we propose real-time location searching system for book collections (BLSS), which we can get the location of books in bookshelves. This system helps us to find the book among many books in huge bookshelves in real-time. this system has book locations and its ID that detected by QR code pasted in the backborn of a book from the picture captured with web camera. The books related with ID are stored in the database that we call LDB (location database) in location and ID pair form. The database is updated in a few seconds interval, by capturing pictures with web cameras, and detecting and decoding QR code. Now BLSS web interface guides us to search the book location in detail. BLSS finds the location of books specified with search condition by users, refering LDB and ADB (all database) which has all books in a book collection. BLSS can also be applied to warehouses of goods.

2 - Bunkering port and quantity determination in a hub and spoke system

Danijela Tuljak-Suban, Valter Suban

Choosing an optimal bunkering port which minimises increases in the operating costs in a hub and spoke system is a problem which can be dealt with using multi-criteria decision making. Furthermore, the criteria used for choosing a bunkering port are not standard, but are generally related to local particularities; some criteria are quantitative while others are qualitative. It is therefore necessary to create a model which takes into consideration such features. Until now researchers have only taken into consideration the factor of bunkering port location optimisation, regardless of bunker quantity. Theoretically, a ship could bunker

95% of her bunker tank capacity. This situation is possible if the ship is empty, partly loaded or loaded with light cargo. All ship capacities are limited with volume capacities or weight capacity, so-called deadweight (DWT). DWT represents all weight on board including cargo, bunker, other liquids and constant weights. This can never be exceeded for reasons of ship safety. The most important cargo on the part of the ship's operative is deadweight cargo capacity (DWCC), which generates revenue. The DWCC of a vessel expresses how much pure cargo can be loaded without the aforementioned weights. The presentation will define a set of the most commonly used criteria, obtained based on a literature review for the determination of optimal bunkering port and criteria for the determination of the optimal quantity of bunker.

3 - The design of transfer timetables for public transits
Jin-Yuan Wang, Yu-Fan Hsu

Timetables are very essential for promoting the usage of public transits. Transfer is unavoidable activity for taking public transits. The transfer waiting time could influence passenger's willingness to use the public transportation significantly. A well-designed timetable is considered an effective mean to reduce transfer waiting time and to increase usage rate of public transit. The main work of this research is to develop a linear programming mathematical model to generate timetables for two public transit routes, one major backbone route and one minor feeding route, with the objective of minimizing the total transfer waiting time and satisfy all the required constraints, such as the limit of number of available vehicles and the required headways. In order to meet various practical needs, we develop one basic model and several variations to accommodate different circumstances. They are min-max model, peak and off-peak model, and fixed time model, respectively. Each of these models addresses different practical operation circumstances. We collect data of one railway route and three feeding bus routes from real world operators and use CPLEX as the solver. The testing results show that the timetables generated by the proposed models are all better than the existing ones. The mean waiting time can be reduced from about 30% to 50%.

4 - Robust mathematical models associated with negotiating financial investments in large-scale transportation projects
Alexander Belenky, Gennady Fedin, Alain Kornhauser

For two large-scale transportation projects, a robust approach to modeling negotiations among the public sector and several competing/cooperating entities representing private investors and private companies interested in managing/operating the projects is proposed. The first project deals with developing a regional freight transportation infrastructure, and it envisions a) developing new transport hubs and access roads to them, along with modernizing the existing ones, b) rerouting cargo flows in the region, c) establishing flexible tariffs for moving cargoes via the region and for storing cargoes at the hubs, and d) choosing tax rates for cargo services in the region to keep this infrastructure both attractive for cargo owners and competitive to the neighboring regions. The second project aims at choosing an optimal structure of a regional chain of recharging stations for electric cars and cars with hybrid engines proceeding from a) estimates of the expected traffic of such cars and its percentage in the whole traffic on all the major roads in the region, b) electric energy prices in each part of each 24-hour time segment, c) the use of renewable sources of energy and electricity storing systems at the stations, and d) financial conditions conducive to potential private investors and encouraging crowdfunding to the chain. In both projects, equilibrium strategies of the negotiating parties turn out to be those in three-person games on polyhedral sets of player strategies.

■ TE-05

Tuesday, 16:45-18:15 - 203

Stochastic modeling and simulation in engineering, management and science 3

Stream: Stochastic modeling and simulation in engineering, management and science
Invited session
Chair: *Gerhard-Wilhelm Weber*
Chair: *Derya Dinler*
Chair: *Alan Wan*

1 - Computing probabilities of Boolean functions of sets in the n-space, with application of the multivariate quantiles: p-level efficient points
Jinwook Lee, Andras Prekopa

Computing and bounding of probabilities of Boolean functions of events, repeated by sets in Rn, typically done in such a way that we compute low order probabilities and infer to higher order ones. In this paper we do the opposite: based on the knowledge of some low order probabilities we easily compute higher order probabilities to use in the calculation. Our sets are orthants in Rn and N, the number of them, is large (N > n). Assuming the knowledge of the n-order probabilities, we easily compute larger order probabilities and the binomial moments of the number of occurrences to use them to obtain exact values and bounds of the Boolean functions of the events. Numerical examples and application of the multivariate quantiles of a discrete distribution (p-level efficient points) are presented.

2 - Numerical methods to deal with GI/G/1 queues when inter-arrival times and/or service times have geometric tails
Javad Tavakoli, Winfried Grassmann

We discuss a number of numerical methods to find the distributions of the waiting time, the idle time, and the length of discrete-time GI/G/1 queues when inter-arrival or service time distributions have geometric tails. First, we find the waiting time and idle time distributions by a modification of an algorithm suggested earlier by Grassmann and Jain. Next, we present three methods for finding the distribution of the number of all elements in the system. In the first method, we formulate a Markov chain with three state variables - the length of the line, the time since the last arrival, and, if the server is busy, the time since service started. The next method uses a Markov chain embedded at the time service has started. Finally, we show how the distribution of the number in the system can be found from the waiting time distribution. Numerical and theoretical arguments show that this last method is the most efficient one, often by several orders of magnitude.

3 - Network consolidation through a modified assignment algorithm
Alexander Barclay, John Yannotty, Quentin Donofrio

Most modern businesses incur expenses associated with networks essential to operations. Network consolidation is a mechanism for these businesses to minimize costs. Our research studied network consolidation for businesses constrained by location, service demand, and service capacity. An algorithm was implemented for optimal consolidation of a constrained network that would minimize cost while retaining prescribed service levels. The model is a modified assignment algorithm in which the constraints come from network specifications and service levels. The algorithm is designed to eliminate underutilized high-cost providers. Consumer demand by region is satisfied with the minimal amount of providers resulting in the overall minimal network cost. Initially, consolidation of a Federal DSL network resulted in a 70 percent reduction in annual expenses. Service provided remained the same while network growth was enabled. Reducing total network cost while holding the number of customer's steady resulted in cost reductions for the customer and profit increases for the provider. The preliminary study was previously presented at the 2016 Annual INFORMS Meeting. A rigorous sensitivity analysis and simulation provides a predictive representation of the algorithm's ability to react to network growth. The model is able to predict network growth and future consolidation. This predictive cost model will result in controlled lower costs for both the provider and the customer.

4 - Reducing simulation input-model risk via input model averaging
Alan Wan, Barry L. Nelson, Xinyu Zhang

Input uncertainty is an aspect of simulation model risk that arises when the driving input distributions are derived or "fit" to real-world, historical data. While there has been significant progress on quantifying and hedging against input uncertainty, there has been no direct attempt to reduce it. In this paper we show that frequentist model averaging can be a provably effective way to create input models that better represent the true, unknown input distributions, thereby reducing model risk. Input model averaging builds from standard input modeling practice, and requires no change in how the simulation is executed nor any follow-up experiments. We provide theoretical and empirical support for our approach.

■ TE-06

Tuesday, 16:45-18:15 - 204A

Performance measurement in humanitarian logistics

Stream: Humanitarian logistics
Invited session
Chair: *Tina Wakolbinger*

1 - Dynamic allocation of NGO funds among program, fundraising, and administration
Telesilla Kotsi, Goker Aydin, Alfonso Pedraza-Martinez

Non-governmental organizations (NGOs) report three distinct types of spending: program spending to deliver services directly to beneficiaries; fundraising spending to raise donations; and administrative spending, which refers to all other overhead. Understandably, watchdog organizations (e.g. Charity Navigator) give higher ratings to NGOs that allocate more of their budget to the program, which brings an immediate reward by meeting the needs of beneficiaries. However, fundraising and administrative spending are also necessary for NGOs to maintain the effectiveness of their programs. In particular, fundraising helps to increase the NGO's future budget (e.g. by improving its donor base), while administrative spending helps to make future program spending more impactful (e.g. by hiring experienced staff or by building better infrastructure). We model this trade-off using dynamic programming to determine the optimal allocation of funds over time. We study how the optimal allocation of an NGO changes in response to changes in fundraising efficiency (the funds raised per dollar spent on fundraising) and return on program spending (a measure of needs met per dollar spent on programs). We calibrate our model using real-world data of NGOs that reveal insightful patterns e.g. cases when NGOs should prioritize program spending at the expense of fundraising and administration, and cases when the prioritization of fundraising and administration is preferred.

2 - A framework for outsourcing humanitarian logistics activities
Tina Wakolbinger, Timo Gossler

Outsourcing of logistic activities during humanitarian aid operations is gaining increasing attention both in academics and in practice. It is seen as an important instrument to increase the efficiency of relief operations and handle the growing number of disasters. However, a literature review has revealed the absence of an integrative framework for outsourcing in humanitarian logistics as an important research gap. In this article, we try to lay the foundation for future research on outsourcing in humanitarian logistics by defining the term and by establishing the required activity framework. Based on current literature and expert interviews we present options for outsourcing of activities in humanitarian logistics and describe relevant dimensions for classifying these options.

3 - Scenario-based multi-stage disaster preparedness measurement model for high hazard potential regions
Mohammadmehdi Hakimifar, Mehdi Ghazanfari, Tina Wakolbinger, Fuminori Toyasaki, Fuminori Toyasaki

The number, costs and casualties of natural disasters are growing. Disaster preparedness is an important topic in humanitarian operations studies and different frameworks have been developed so far considering a variety of dimensions. This paper provides a systematic overview of these models, extracts the dimensions of disaster preparedness and classifies them into three groups: Hazard Knowledge, People and Properties, and Management and Coordination. It then incorporates these dimensions into a scenario-based multi-stage model of disaster preparedness. This model allows communities to measure their preparedness based on four dimensions: hazard knowledge, mitigation capabilities, resource preparedness, and management performance.

■ TE-07

Tuesday, 16:45-18:15 - 204B

Inventory routing 2

Stream: Vehicle routing
Invited session
Chair: *Marcus Poggi*

1 - A matheuristic algorithm for the multi-depot inventory routing problem
Annarita De Maio, Luca Bertazzi, Leandro Coelho, Demetrio Laganà

In this work a matheuristic for the Multi-Depot Inventory Routing Problem (MDIRP) in a mega-city context is presented. The MDIRP is an NP-hard problem that aims at optimizing inventory and transportation costs in an integrated way. With respect to the state of the art, a different context is presented, characterized by the high level of urban environment complexity. In order to face this situation, the urban space is partitioned into districts allowing to create clusters and to generate sets of feasible routes for the MDIRP. A two-phase matheuristic algorithm is presented: in the first phase an integer program is used to build clusters; while in the second phase a route generation is designed to construct a set of feasible routes for each cluster. More emphasis is devoted to simultaneously balance several factors that impact the clustering and route construction phases: distances, demand and inventory levels, time horizon extension, vehicle capacity. Computational results are presented.

2 - Efficient routes in a periodic inventory routing problem
Rosario Paradiso, Luca Bertazzi, Geoffrey A. Chua, Demetrio Laganà

In this work, a mixed-integer linear programming formulation for a Periodic Inventory Routing Problem, based on routes variables, is presented. In particular, a product has to be shipped from a supplier to a set of customers over a infinite time horizon. Given the plan periodicity, the problem is to determine a periodic shipping policy that minimizes the sum of transportation and inventory costs at the supplier and at the customers per time unit. Due to the difficulty to solve a formulation with all the possible feasible routes, the aim of this work is to find the minimal set of routes that allows to have the best possible worst-case performance ratio, allowing to solve the problem with a lower number of integer variables ensuring the quality of the solution over a threshold.

3 - On the complexity of some special cases of the inventory routing problem
Annelieke Baller, Martijn van Ee, Leen Stougie

In the Inventory Routing Problem (IRP) inventory management and route optimization are combined. The Traveling Salesman Problem (TSP) is a special case of the IRP, hence the IRP is NP-hard. We consider special cases of the IRP other than TSP for which it is not clear in advance whether these problems are easy to solve or NP-hard. First, we study cases in which the metric space is a half-line. The problems differ in the number of vehicles, the number of days in the planning horizon and the processing times of the customers. Our main result is a polynomial time dynamic programming algorithm for the case with uniform processing times and a planning horizon of two days. Second, for a family of problems we show that the complexity is comparable to the complexity of the Pinwheel Scheduling Problem which is long-standing open question. Third, NP-hardness is shown for problems with non-uniform processing times. Finally, we study the problem with one vehicle, an infinite planning horizon, uniform processing times and customers located in the Euclidean plane. Instead of computing the routing cost exactly, we approximate the routing cost avoiding immediate NP-hardness via the TSP. We show that with a given route cost approximation this problem is strongly NP-hard.

4 - Solving an inventory routing problem via Benders decomposition
Marcus Poggi, Rafael Martinelli, Fabiàn Penaranda

Inventory Routing Problems(IRPs) can be viewed as a periodic vehicle routing where the deliveries to clients on each period are chosen in order to balance inventory cost and routing costs. We address a IRP where clients' have demands to fulfill over a multi-period horizon, there are a fixed number of identical vehicles and the objective is to find the deliveries for each client on each period that minimizes the total inventory and routing cost. This work explores the inherent decomposition of the IRP into the two classical problems it combines. The Benders decomposition framework we construct chooses the inventory manegement problem as master for its linking role in the IRP. As a result the methodology developed is required to deal with an ensemble of challenges that comes from having a capacitated vehicle routing as subproblem (CVRP). The first challenge is the integrality of the CVRP. The second one comes from having master problem variables in the left hand side of the subproblem formulation. Finally, in order to use state-of-the-art algorithms for the CVRP, the use of column generation algorithms in the subproblem must be addressed. To overcome these hurdles we follow the steps in Zou, Ahmed and Sun(2016) and devise cuts that approximate the Benders optimality cuts. The resulting algorithm combines branch-and-cut, branch-and-price and route enumeration. Experiments over literature instances reveal the competitiveness of the proposed methodology.

■ TE-08

Tuesday, 16:45-18:15 - 205A

Dynamic programming and Markov decision process

Stream: Dynamical systems and mathematical modelling in OR
Invited session
Chair: *Yukihiro Maruyama*
Chair: *Masayuki Horiguchi*

1 - Analyses of the cover time of deterministic random walks
Takeharu Shiraga

A random walk is intensively studied as a useful approach for network exploration because of its simplicity, locality and robustness in changing networks. The cover time, which is the expected time until every vertex has been visited, is a key measure for network exploration by a random walk, and has been well investigated. Recently, a deterministic random walk, which is a deterministic process analogous to a random walk, has been studied as an alternative of a random walk in some contexts such as network exploration and simulations of physical phenomena. In particular, the cover time of a deterministic random walk corresponding to a simple random walk (called rotor-router model) has been investigated from the view point of a deterministic graph exploration. However, nothing is known about the cover time of deterministic random walks corresponding to general transition probabilities, as far as we know. This paper is concerned with the cover time of deterministic random walks for general transition probabilities. First, we give a general upper bound of the cover time of deterministic random walks for any ergodic and reversible transition matrix. This bound improves the existing result on the speed up ratio of the rotor-router model as increasing the number of tokens in general graphs. Moreover, we show that a deterministic random walk corresponding to a fast random walk using local degree information has a faster cover time than a rotor-router model on some specific graphs.

2 - An approximate optimization algorithm in Markov decision processes and its application to a two-stage production and inventory system
Koichi Nakade, Shizuru Tsuchiya

Theory and algorithms of Markov decision processes are useful for analyzing optimal control of stochastic dynamic systems, but the classical computation method has a deficit on the curse of dimensionality. Thus, several kinds of computation methods for deriving approximate optimal control are investigated. Arruda and Fragoso (2015) develop a two-phase time aggregation algorithm on an average cost minimization problem. They show the convergence to the optimal policy of this algorithm under ergodic assumptions, but give a simple numerical example. In this talk, we apply this algorithm to a two-stage production and inventory system with advance demand information. This algorithm is, however, very slow to converge to an approximate optimal policy. We discuss the modification of this algorithm to apply it to this system. One main modification is the extension of a subset consisting of core states during the proceeding of computation by the algorithm. The derived approximate optimal policies are compared with near-optimal base stock policies and extended Kanban policies by numerical experiments.

3 - Strong representation by non-deterministic sequential decision process and its applications
Yukihiro Maruyama

This paper makes clear the relation between a given non-deterministic discrete decision process (nd-ddp) and a subclass of non-deterministic monotone sequential decision process (nd-msdp) for which the functional equation of non-deterministic dynamic programming is obtainable. We show a strong representation theorem for the subclass of the nd-msdp. The strong representation provides a necessary and sufficient condition for the existence of the subclass of nd-msdp with the same set of feasible policies and the same cost value for every feasible policy as the given process nd-ddp. Further, the theorem is applied to some discrete non-deterministic optimization problems, for example, non-deterministic shortest path problem.

4 - Bayesian control chart with unknown parameter
Masayuki Horiguchi

In this paper, we consider quality control model based on Bayesian inference. Sequential sampling problems are formulated as optimization models of sequential decision processes and in many preceding studies optimal adaptive policy are derived by using Bayesian inferences. We consider on making the control chart on the basis of both statistic and economic standpoint. To realize this management, it is needed to consider the model as sequential decision process and the model is constructed by way of having cost structure of sampling and the states of system which are partially observed and move from in-control state to out-of-control followed by transition law. Makis (2008) considered this model under the assumption that the state moving from in-control to out-of-control is occurred with the exponentially distribution and known parameter. He formulates this multivariate control model as Markov decision process (MDP) and he derived the existence of optimal control policy and by this result, he proposed a method of multivariate control charts. In this paper, we consider the Makis' control chart with unknown parameter. By Bayesian analysis we compute a posteriori distribution on the basis of both the observed information of each steps and updating of priori distribution of unknown parameter. Applying the limit theorem for posteriori distribution we construct useful adaptive policy and utilize it in order to make control charts to control the system.

■ TE-09

Tuesday, 16:45-18:15 - 205B

Primal integer optimization

Stream: Discrete optimization in logistics and transportation

Invited session

Chair: Issmail El Hallaoui

1 - Integral simplex: An introduction

Samuel Rosat, Issmail El Hallaoui, Francois Soumis

The Integral Simplex is a primal algorithm best suited for 0,1-linear programming. It is based on iterative improvements of a given initial integer solution by performing (linear) simplex pivots. At each step, a subproblem (SP) is solved to determine a feasible improving direction, i.e., such that a nonzero step can be taken in that direction without violating the linear constraints, and that strictly improves the cost of the current solution. The bottleneck of the method is to ensure that following this direction leads to an integer solution. Branch and bound, cutting planes or other techniques can be necessary to palliate that problem, but a simple branching method is sufficient to obtain good results on many large scale problems. In this talk, we give an introduction to this algorithm. We present it in a primal form and discuss some theoretical and practical features. We give a geometrical interpretation of the different problems and concepts. Then, we present different methods to foster directions that lead to integer solutions based on cutting planes and normalization weights. We show results on large scale set partitioning instances from industrial scheduling applications (up to 1600 constraints and 570000 variables).

2 - Integral simplex using doule decomposition

Omar Foutlane, Issmail El Hallaoui

We present an Integral Simplex Using Doule Decomposition algorithm (ISU2D). ISU2D implements a dynamic self-adjusted decomposition based on inference procedure to find sets of orthogonal descent directions at each iteration. The idea is to project some useful information to get potential small subproblems. We solve then the obtained subproblems in parallel to get descent direcions leading to an improved integer solution and we loop until optimality. We also present some strategies to speed-up ISU2D. Computational tests are carried out on aircrew and bus drivers scheduling.

3 - Integer column generation

Tahir Adil, Issmail El Hallaoui, Guy Desaulniers

Integer column generation using decomposition (ICG) is a new primal method that aims to solve the popular set partitioning problem. This method finds a sequence of integer solutions, with non-increasing cost, leading to optimal or near-optimal solutions in reasonable time. Potential columns favoring integrality are generated using a suited dual vector. Some acceleration strategies improving the effectiveness of ICG will be discussed. Computational experiments on some large-scale bus drivers scheduling and aircrew pairing problems will be presented. The results obtained demonstrate the efficiency of ICG

4 - An improved version of the integral simplex using decomposition algorithm

Zaghrouti Abdelouahab, Issmail El Hallaoui, Francois Soumis

Integral Simplex Using Decomposition (ISUD) is a method that efficiently solves set partitioning problems for the transportation industry. It is an iterative method that starts from a known integer solution. At each iteration, the method decomposes the original problem into a Reduced Problem (RP) and a complementary Problem (CP). Given an integer solution to the original problem, RP/CP find a descent direction having the minimum ratio between its cost and its size. Making some branching if necessary, this leads to an improved integer solution. The method then loops on, decreasing the cost each time, until an optimal or near-optimal solution is reached. As a new version of ISUD, we introduce a modified model for CP and a new algorithm that improve both quality and performance. The new algorithm finds descent directions that minimize the ratio between the cost of the direction and an over-estimation of the size of the next solution. The new version presents higher chances of finding improved integer solutions without branching. We present results for the same large instances (with up to 570000 columns) previously used to test ISUD. For all the instances, optimality is reached all the time while, at least, five times speed-up factor is gained. In addition to its performance, the most important advantage of this new version of ISUD is that it opens the possibilities of its extension to arbitrary binary problems instead of remaining specific to set partitioning problems.

■ TE-10

Tuesday, 16:45-18:15 - 205C

Combinatorial and mixed-integer multiobjective optimization

Stream: Multiobjective optimization methods and applications

Invited session

Chair: Martin Kidd

1 - vOpt: An open source software environment for multiobjective mathematical optimization

Xavier Gandibleux, Gauthier Soleilhac, Anthony Przybylski, Stefan Ruzika

vOpt is an open source software environment devoted to the optimization of multiple objectives (MO) mathematical programming problems belonging to (1) linear problems (MOLP), (2) combinatorial problems (MOCO), (3) integer problems (MOIP), and (4) mixed integer linear problems (MOMILP). It aims to provide an easy and convenient way to experts and non-experts for modeling and solving MOLP / MOCO / MOIP / MOMILP. vOpt is currently developed in the context of the ANR-DFG research project devoted to "Exact Efficient Solution of Mixed Integer Programming Problems with Multiple Objective Functions" where an output is a software prototype devoted to MOMILP. It runs under the operating systems linux and macOSX. vOpt is designed as a backbone which integrates (1) software components (solver's independant) implemented in C/C++ language and (2) two packages implemented in Julia language. The two packages act as interface between end-users' applications written in Julia and the library of software components. Julia (http://julialang.org) is a young programming language; it has been chosen because it is a free, open source, high-level, high-performance dynamic programming language for scientific computing. Its syntax is familiar to users of other technical computing environments. vOpt contains three kinds of software components: (1) ad-hoc MO independant solvers, (2) generic MO independant solvers, and (3) generic MO primitives. The talk presents the current version of vOpt.

2 - A many-objective evolutionary algorithm with fixed reference points and path relinking
Mert Sahinkoc, Ümit Bilge

It has been shown in the literature that the methods for multi-objective optimization including multi-objective evolutionary algorithms often suffer scalability issues when number of objectives is high. This fact has lead into a new research area in which the optimization problems with number of objective functions higher than three are considered. These problems are called many-objective optimization problems and the associated studies try to characterize and overcome the challenges posed by the high number of objectives. Large number of non-dominated solutions, inefficiency of conventional recombination operators and difficulty in maintaining diversity for a good and well-spread approximation of the true Pareto front are among these challenges. This paper addresses these issues and proposes a successful many-objective algorithm with a combination of features that can contribute to the present methodologies. Our proposed algorithm uses elitist non-dominated sorting based on reference points that are mapped onto a "fixed hyperplane" integrated with path relinking recombination scheme and complementing selection mechanisms. 0-1 Knapsack problem which is extensively studied in the field of multi-objective evolutionary optimization during the recent years is chosen as the benchmark. Numerical experiments with 4-15 objectives yield promising results in comparison to a set of existing multi-objective evolutionary algorithms.

3 - Multi-agent, two-criteria: Optimization total the number of tardy jobs and the makespan on identical parallel processors
Tran Van Ut, Ameur Soukhal, Thanh Thuy Tien Ta

In the multi-criteria scheduling problem field, multi-agent is a new direction research for real requirements. Actually, efficient management of large-scale job processing systems is a challenging problem, particularly in the presence of multi-users. In our research case, the objectives functions are miniminzing the makespan (the completion time) and minimizing the total number of tardy jobs on identical parallel machines. The scheduling problems in which agents have to share the same set(s) of resources are at the frontier of combinatorial optimization and cooperative game theory. This problem is NP-hard. First, two mixed integer linear programming models are proposed to calculate exact non-dominated solutions. Second, we had proposed two polynomial heuristics that are based on the rules Shortest/Longest Processing Time (S/LPT) and First Available Machine (FAM). Third, we had proposed two methods pseudo-polynomial heuristics that combine the polynomial heuristics and dynamic programming. Last, we propose two new matheuristics that combine the polynomial heuristics and the mathematical programming. Experimental results are conducted to measure the solution quality given by heuristics, matheuristics and the results are discussed.

4 - A new criterion space search method for finding a discrete representation of the nondominated set in biobjective mixed integer programming
Martin Kidd, Richard Lusby, Jesper Larsen

We consider the problem of finding a discrete representation of the nondominated set in biobjective mixed integer programming. We propose a method to generate a small number of points, where we use a desired cardinality of the representation as a stopping criterion as opposed to a desired quality level. We consider two quality measures that have become standard in the literature, namely coverage and uniformity, and we show that the optimization problems of minimizing the coverage error of n points and maximizing the uniformity level of 2n+1 points are duals of one another. By solving both problems, an optimality gap is therefore obtained, and in particular we show that this gap is closed if a representation can be found in which consecutive points are equidistant in the criterion space. Inspired by this result, we develop a criterion space search method that attempts to construct a (nearly) equidistant representation of a given cardinality by utilizing the space division technique behind Voronoi diagrams. The method is easy to implement, and relies only on the availability of a black-box solver. We show on a set of biobjective mixed integer programming benchmark instances that this method significantly outperforms methods from the literature both in terms of coverage and uniformity.

■ TE-11

Tuesday, 16:45-18:15 - 206A

Supply chain coordination 2

Stream: Supply chain management
Invited session
Chair: Mingyuan Chen

1 - Perfect coordination in supply chain under information asymmetries
Dimitris Zissis, George Ioannou, Apostolos Burnetas

We consider a two-node supply chain (supplier- retailer), in which both nodes have private information that affects their reservation levels and the way of deciding their actions. The nodes are forced to interact with each other because no alternatives for external interaction are allowed. The supplier produces a single product and cannot accommodate inventory; thus, supplier works under the lot-for-lot fashion and completed lots are directly forwarded to the retailer. The latter faces the EOQ model; i.e. the retailer has to decide on the lot size optimize his utility function. Shortages or backorders are not allowed. Both nodes are risk neutral, rational and act in a decentralized manner. We capture information asymmetry assuming that the supplier's production cost and the retailer's holding cost are random variables. Our objective is to examine if the nodes could coordinate their decisions in a decentralized chain. To reach coordination we allow the nodes to communicate before they finalize their strategies via a reliable mediator concerning any private information they may possess. The mediator designs a mechanism to minimize the overall cost using quantity discounts. Thus, the supplier provides to the retailer a quantity discount to induce retailer to order the joint optimal quantity because it is in his self-interest. We prove that coordination is feasible via quantity discounts and node communication, and devise exact expressions for the optimal nodes' strategies.

2 - Supply chain coordination under asymmetric information and partial vertical integration
Grigory Pishchulov, Knut Richter, Sougand Golesorkhi

Supply chain contracting is known to suffer from inefficiency in the presence of asymmetric information. Full vertical integration would eliminate the informational inefficiency but can be strategically undesirable. Yet today's supply chain partnerships exhibit a certain degree of partial vertical integration via equity ties between the firms. Such governance forms received little attention in supply chain research. Management literature suggests that partial vertical integration may help the firms to ease contracting problems by aligning their incentives, and thus improve the total surplus. We address this proposition by studying a model of a partially integrated supply chain in which the buyer holds an equity stake in the supplier. We adopt the operations planning perspective and investigate contracting between the firms within the classical joint economic lot size framework. We demonstrate that partial integration can be sufficient for fully eliminating informational inefficiencies, and thus achieving coordination. However, contrary to intuition, a tighter integration may actually harm supply chain performance and lead to coordination failure. We explain the economic mechanism at work and investigate it analytically and numerically. Our results characterize robustness of coordination and allow determining an optimal degree of partial vertical integration from the operational standpoint.

3 - Information sharing and information errors in a two-level supply chain
Jizhou Lu, Gengzhong Feng, Kin Keung Lai, Stephen Shum

Enterprises in developing economies may not possess sophisticated supply chain information systems. This can lead to two types of information errors: transmission error that occurs in the transmission of information from the retailer to the manufacturer, and source error that occurs during the collection and input of data at the retailer. In this paper, we study the value of information sharing in the presence of either or both types of information errors. In particular, when information is shared, the manufacturer may use both the shared demand information and the retailer's order quantity to make decisions, or she may rely solely on the shared demand information and disregard the retailer's order quantity when doing forecasting. We analyze the values of information sharing for both settings, and characterize the lowest-cost information sharing strategy for the manufacturer. Our results suggest that transmission error and source error have significantly different impacts on the value of information sharing and the manufacturer's optimal strategy.

4 - Modeling supply chains with technology transfer and market sharing
Mingyuan Chen

We investigate the effect of technology transfer on supplier-retailer relationship in a supply chain system involving technology transfer and market sharing. We consider that technology transfer decisions will be made by the original equipment manufacturer (OEM), the key technology owner. We propose a mathematical model and make analysis on: (i) a supply chain without technology transfer, (ii) a supply chain with technology transfer but without supplier's market sharing, and (iii) a supply chain with technology transfer and supplier's market sharing. A numerical example with sensitivity analysis is presented to illustrate the theoretical findings and analytical results. We show that the optimal profit of the OEM with technology transfer and market sharing is typically greater than those without technology transfer or market sharing. The analysis also provides the conditions for the original equipment manufacturer to enhance technology transfer when the supplier's market is open to the OEM's final products. The proposed model is illustrated with an example in aerospace industry and can be extended for solving similar problems in other industries.

■ TE-12

Tuesday, 16:45-18:15 - 206B

AHP/ANP

Stream: Multiple criteria decision making and optimization (contributed)
Contributed session
Chair: Josef Jablonsky

1 - Computing the principal eigenvector of positive matrices by the method of cyclic coordinates
Kristóf Ábele-Nagy, János Fülöp

We are proposing a simple method to calculate the principal eigenvalue of positive matrices based on the Collatz-Wielandt formula. The minimax property of the principal eigenvalue makes it possible to formulate a multivariate optimization problem where the elements of the principal eigenvector are variables. This problem can be solved in an iterative way with the cyclic coordinate method. The algorithm is customized for large matrices. Although the method is quite universal, our intended field of application is obtaining the principal eigenvector of pairwise comparison matrices, which is the weight vector when using the Eigenvector Method. A possible extension of this method deals with missing elements in the matrix. In this case the missing elements are additional variables. An application of this method is computing the principal eigenvalue and optimal completion of incomplete pairwise comparison matrices.

2 - Identifying thresholds of acceptance for inconsistent pairwise comparisons based on probabilistic reasoning
Sajid Siraj, Matteo Brunelli, Alan Pearman

As pairwise comparative judgements in multi-criteria problems are often found inconsistent, it is important to have a justified threshold of acceptance or rejection for these judgements. In this context, Consistency Ratio is the most widely used measure with the threshold of 0.1. We investigate this and other widely-used inconsistency measures using Monte-Carlo approach in order to explore the underlying distributions, and propose a family of thresholds based on probabilistic reasoning. We further study and show that the idea of probabilistic reasoning can be extended to identify the levels of inconsistency at individual judgements level.

3 - Muticriteria analysis with ANP to strengthen decisions about sustainable electrical energy generation in Mexico
Alan Monterrubio, Mayra Elizondo

The consumption of electrical energy is an indispensable need nowadays and its current importance is represented since it is one of the main and more used energy sources in the world. Communications, transport, food supply and most of the services provided in residences, offices and industries depends on a safe and reliable electrical energy supply. Previous researches have suggested that the average consumption of electricity per inhabitant is around ten times greater in the industrialized countries than developing countries, so it can be stablished that electrical energy consumption is related directly to the economy performance of a country. In Mexico, such consumption has increased very quickly in the recent years. The problem of satisfying this consumption is complex, due it has to considered under long term visions and into a sustainability frame that needs to embrace systemic aspects of social justice, understanding the paper of politics, as well as, the management and implementation of action processes. For these reasons, it is necessary apply Multicriteria Decision Making (MCDM) as an appropriate methodology which takes advantage of a multidiscipline approach and can be used to solve emerging conflicts. The present paper pretends to show the potential of Analytic Network Process (ANP), as a method that supports a multicriteria decision making process for a renewable energy sources selection that might be used in Mexico as an alternative of to fossil fuels.

4 - AHP model for performance evaluation of employees in a management consulting company
Josef Jablonsky, Lucie Lidinska

The article is focused on a pilot application of the analytic hierarchy process (AHP) to the performance evaluation of employees of a management consulting company. Performance evaluation of employees is a complex task that must take into account various aspects and evaluation criteria. Moreover, each employee of the company participates during the period being considered in several projects and his or her overall performance over the period is an aggregation of individual performances in particular projects. This aggregation is based on the weights of the projects that usually depend on man-days the employees participated in the projects or their financial contributions. AHP is a tool for structuring and analysis of complex decision making problems and seems to be an ideal tool for this task. The proposed AHP model combines relative and absolute measurement and allows deriving overall performance scores of the employees through a simple MS Excel application easily and quickly without the necessity to use any specialized software tool.

■ TE-13

Tuesday, 16:45-18:15 - 207

Applications of MCDA

Stream: Applications of MCDA
Invited session
Chair: Theodor Stewart

1 - Multi-criteria analysis as a tool to enhance intermodality and promote ticket integration in public transport
Klaas De Brucker

To enhance modal shift from car to public transport, policymakers promote the idea of intermodality (i.e. using different modes of transport on one journey). One technique aimed at facilitating intermodality in public transport is ticket integration, allowing passengers to use several modes of public transport operated by different operators in a single city, region or country using a single ticket. In this contribution we use multi-criteria analysis (MCA) to identify challenges associated with projects promoting ticket integration. Based on a literature review, an analysis of case studies (London, Paris, the Netherlands, Stockholm and Brussels) and interviews, we conduct a preliminary multi-actor MCA. First, we identify the relevant stakeholders and the objectives they want to achieve through projects linked to ticket integration. The objectives are clustered so as to correspond to the goals pursued by particular stakeholders in the decision-making process. Based on the literature and case studies we discuss alternative ways of implementing ticket integration. Three main categories can be identified: technical integration, commercial integration and full integration. Stakeholder concerns identified include revenue sharing, access to big data and privacy issues. The MCA will be used to evaluate and learn from existing alternatives in order to design better systems that fully support intermodality and contribute to stakeholders' objectives in the future.

2 - Multicriteria assessment of agricultural biomass for energy and material use
Jutta Geldermann, Meike Schmehl

Energy and material product systems based on renewable resources have different and partly opposing effects on sustainable development throughout their lifecycles. In the example of agricultural land as a common basis of comparison, five alternative product systems of renewable resources are assessed by the multi-criteria outranking methodology Preference Ranking Organisation METHod for Enrichment Evaluations (PROMETHEE). Within the multi-criteria model, a criteria hierarchy comprising ecological, economic and social impacts is developed. The alternatives cover the broad scope of agricultural biomass use for energy and materials in Germany. The required data for the determination of the criteria values stem from heterogeneous data sources, e.g. commercial data bases on life cycle assessment, expert knowledge, literature studies and direct measurements. As these data are not homogenous and consistent for all criteria and all alternatives, data quality assessment is necessary within multi-criteria decision support. Thus, the pedigree matrix developed from Funtowicz and Ravetz (1990) is adapted and integrated into the PROMETHEE-approach. In this way, the resulting preference flows can be characterised by their data quality.

3 - Perceived taste of wine goes beyond the tongue: The impact of color
Mohammad Ghaderi, Nuria Agell

Perceived taste is a complex cognitive task which goes beyond the ingredients. In addition to ingredients, studies show that aesthetics such packaging, logo design and colors substantially contribute to the perception of taste. People tend to associate different colors with the basic tastes such as sweet, sour, salty, bitter and possibly umami (Spence et al, 2015). Although the significance of colors influence on taste perception is confirmed by several studies, yet little is known about the extent to which colors contribute to the perceived taste. This research follows a multiple criteria decision aiding approach to investigate the impact of color on perceived wine taste. To this aim, a recently introduced preference disaggregation framework that is flexible in handling non-monotonic attributes is employed (Ghaderi et al, 2016).

■ TE-14

Tuesday, 16:45-18:15 - 305

Green logistics 1

Stream: Sustainable logistics
Invited session
Chair: Maximilian Schiffer

1 - Optimal charging station placement in a free-floating electric car sharing system
Georg Brandstätter, Markus Leitner, Mario Ruthmair

In recent years, free-floating car sharing systems have become a popular mode of transportation within urban areas, as they allow their customers similar flexibility to owning a car without the associated costs. Using electric vehicles allows the operator to operate in an environmentally-friendly way, while also improving efficiency. These vehicles must, however, be regularly recharged to ensure that they do not run out of battery. Thus, a network of charging stations must be built within the system's area of operation, where cars can be recharged when they are not in use. Since building and maintaining these stations is costly, placing them effectively is paramount to the economic viability of any free-floating electric car sharing system. We present integer linear programming formulations for solving the problem of finding optimal locations and sizes for charging stations within such a system. Given a limited budget, we want to place them in such a way as to maximize the amount of customer demand that can then be satisfied. We assume that customers are willing to walk a short distance to get to an available car at the start of their trip. They may end their trip anywhere within the system's operational area, but are incentivized by lower rental fees to return cars with low battery to a charging station close to their actual destination. We analyze the performance of our algorithms on a set of benchmark instances that is based on both artificial and real-world data.

2 - Multi-agent modeling and applications for green logistics
Cenk Sahin, M. Ali Ulku

Third-Party Logistics (3PL) companies have focused on minimizing carbon and energy waste in compliance with industry regulations, while maximizing their economic savings. For example, by 2020, FedEx aims 30% fuel efficiency by investing in alternative-fuel vehicles, shifting freight to rail, and optimizing vehicle -routing. In this study, we survey the use and performance of multi-agent modeling systems, particularly, for green 3PL chains.

3 - Is a new definition of intermodal transport interesting for transferring flows from road to more environmentally friendly modes?
Martine Mostert, An Caris, Sabine Limbourg

Road remains the most used mode in Europe. Even if it is appreciated for its responsiveness, flexibility, and quickness, road transport is however responsible for negative impacts on its environment like air pollution or climate change. Intermodal freight transport i.e. the transportation of goods using two or more modes of transport, in the same loading unit, without handling of the goods themselves is identified by the European Commission as an interesting solution for limiting the negative impacts of transport. In the classical conception of intermodal transport, pre- and post-haulage travels are supposed to be short, and to be performed by road transport, whereas the long-haul travel is done using rail or inland waterways (IWW). The objective of this study is to determine the impact on intermodal attractiveness of allowing other combinations of modes than the classical road-rail/IWW-road combination, during an intermodal travel. The goal is to determine the flow distribution of goods between direct transportation by road, rail or IWW, and any combination of these modes using intermodal transport. The novelty consists in taking into account three modes of transport in a mixed integer programming model, and to allow the transfer from any mode to any other at intermodal terminals where these modes coexist. For testing the hypothesis of intermodal transport attractiveness on medium to long distance, the model is applied to the European case study.

4 - Are electric commercial vehicles breaking even - Competitiveness of ECVs in medium-duty logistics networks
Maximilian Schiffer, Sebastian Stütz, Grit Walther

Freight transportation remains as the only sector in which the consumed energy and the generated emissions are still rising. In this course, researchers and practitioners discuss the use of electric commercial vehicles (ECVs) in logistics fleets as sustainable means of transportation in order to realize ambitious governmental targets on greenhouse gas and other noxious emissions. Although big logistics companies realized first pilot projects on electric logistics fleets successfully within short-haul transportation, the acceptance of operating ECVs in mid-haul transportation channels is still missing. Against this background, we investigate the competitiveness of medium-duty ECVs in mid-haul transportation for a logistics network of a large German retail company. We present an aggregated total cost of ownership analysis based on a two-stage decision support system (DSS) with a location-routing component to locate charging stations and a vehicle-routing component for daily vehicle operations. We present a hybrid of adaptive large neighborhood search, local search and dynamic programming that helps to solve large sized instances of the proposed planning task. Using this DSS, we evaluate the competitiveness of ECVs against conventional vehicles based on real world data of the considered logistics network. We show that ECVs are on the verge of breaking even for this specific logistics network and derive managerial insights for further application cases.

■ TE-15

Tuesday, 16:45-18:15 - 307A

Survivable network design

Stream: Graphs, telecommunication, networks (contributed)
Contributed session
Chair: Laura Escobar

1 - Polynomial-time algorithms for combinatorial optimization problems with interval data
Xudong Hu

In this talk, I will present a new approach for dealing with some combinatorial optimization problems with uncertain parameters, where, it is assumed, cost on a link/node in a given network fall into an interval. We introduced two risk models for these problems, proposed polynomial-time algorithms for solving the problems and conducted computational experiments on algorithms proposed. Our theoretical and computational results show the flexibility of this new approach for decision makers at different levels of aversion to risk, as well as satisfactory performance of standard CPLEX solver on our model. Joint work with E. Alvarez-Miranda, Xujin Chen, Jie Hu, Bi Li.

2 - Using the new software GraphsInGraphs to help finding a robust communication network
Eglantine Camby, Gilles Caporossi, Marcia Paiva, Moises Ribeiro, Segatto Marcelo

We present some results on the building of networks with a small average distance and a bounded maximum degree, in order to design efficient data centers. Moreover, due to real technical constraints, we need that the network possesses some robustness, especially after an edge or a vertex removal. As a starting point, we are interested by the Cartesian product graphs and we study the robustness of the Cartesian product after an edge/vertex removal. Some deeper analysis of Cartesian product from the robustness point of view shows that one of its most interesting feature is the presence of a large number of cylces on 4 vertices. Notice that if the presence of these cycles is related to robustness, the minimization of the average distance with bounded maximum degree implies to avoid these subgraphs. The software GraphsInGraphs (GIG) allows the study of a graph depending on their induced subgraphs. In this context, GIG shows that graphs minimizing the average distance with a fixed, bounded maximum degree have girth at least 5. Given these two properties, the search of robust graphs with bounded maximum degree and minimum average distance implies some compromise.

3 - A methodology for transmission expansion planning problem considering reduction of the search space based on angular cuts and minimum effort criterion
Laura Escobar, Rubén Augusto Romero Lázaro

This paper presents a methodology to solve the transmission expansion planning problem of electric power transmission networks, which uses specialized constraints based on angular cuts and the criterion of minimum effort, to reduce the solution space. The long-term planning of electrical transmission systems is an optimization problem of mixed integer linear programming (MILP) of the NP-complete type, for systems of great size and complexity. A mathematical model for the optimization problem is developed and implemented in AMPL, and solved using the CPLEX solver. Test systems from the specialized literature are used to verify the efficiency of the methodology, obtaining interesting results.

■ TE-16

Tuesday, 16:45-18:15 - 308A

DSS technologies

Stream: Decision support systems
Invited session
Chair: Adiel Teixeira de Almeida
Chair: Caroline Mota

1 - Pricing real options premium based on conditional value at risk concept
Kyongsun Kim, Chan S. Park

Considering the risk and uncertainty in project evaluation is an important part of capital budgeting. Traditionally, we begin analyzing project risk by determining the inherent uncertainty in a project's cash flows. The best that we can expect to do is to estimate range of possible future costs and benefits and relative chances of achieving a reasonable return on the investment. Once we obtain the net present value (NPV) distribution by aggregating these periodic cash flows over the investment life, we may be able to determine the NPV at risk through the conditional value at risk (CVaR) concept. It basically calculates the expected loss on an investment, if a certain level of loss is bound to occur over a given time period at a specified degree of confidence. If a typical investor is willing to accept an investment, we may view this amount (CVaR) as his risk tolerance associated with the project. It is important to recognize that real investments are not single decisions without future flexibility, but rather multiple interacting options driven by various uncertainties. Therefore, investors may be interested in hedging this expected loss (CVaR) by using various real options. In this paper, we will explore a procedure to price the value of this changing option for investors whose risk tolerance determined by the CVaR. By determining the correct amount of option premium, we would be able to hedge the risk at the right price.

2 - Relative inner evaluation of an individual by interval group AHP
Tomoe Entani

Writing is one of the communication tools, however, the text on a fact by a writer is not always the same as that by the other. Moreover, it is worth to being respect for the writer's individuality in the text. The text written by non-native speaker makes readers feel unusual, even if there are no evident errors in the sense of basic grammar. An expert can correct it to be perfect, however, the writer often is not fully satisfied with the result and accepts it with the feeling of slight discontent. This study aims to release him/her from the stress of being corrected. It assumes that there are multiple possible choices in correcting a text and aims to give the information to lead an expert. In order for the expert not to rely on his/her standard too much, the objective evaluation on the text is useful. Therefore, this study proposes the method to derive such a relative inner evaluation of a text to keep its individuality and be acceptable for the writer. The individuality in a text is found from its evaluations under the criteria with the comparison of the texts by the others. The text is analyzed under multi-criteria and then its individuality is induced. They are denoted as the interval and crisp weights of the criteria, respectively. This study is based on AHP, where various group decision supports have been discussed. Although most of them emphasize on a group decision, we focuses on an individual decision by referring to a group trend.

3 - Improving educational quality through QFD and AHP
Tetsuro Morita, Yuki Muro, Aozora Kawana, Shin-ichiro Yokoyama, Tsutomu Mishina

Improving quality in education is one of the main goals for many teachers. However, even if only one aspect is considered, such as the improvement of teaching effectiveness, there are many challenging factors that slow the process. These factors are interconnected and bring highly complicated conditions. This paper proposes a logical process for making an effective curriculum which satisfactory reflects any demands regarding quality improving to teaching in a university classroom setting. The methodology employs the idea of QFD (Quality Function Deployment) with improved weight consideration based on AHP (Analytic Hierarchy Process). The factors considered in this paper represent quality items from several layers, such as demand quality and design quality. The purpose of the process aims at altering desired items into those of practical ones for logical and smooth performance. The goal is to achieve a certain level of satisfaction for both instructors and students. The quality items are evaluated and selected based on the order of importance by weights. The basic procedure of altering items includes (1) defining specifically providing services, (2) collecting data, (3) making altering tables for items, and (4) evaluating weights. An example will be shown for bookkeeping classes in series for freshman lectures.

4 - Sequential exploration with geological dependencies and uncertainty in oil prices
Babak Jafarizadeh

The decision to drill or drop exploration wells is complex and multidimensional. Exploration decisions have uncertain inputs; e.g. both the existence of economic hydrocarbon volumes and the future oil prices are uncertain. In a cluster of exploration opportunities, the dependencies among prospects are also important for decision making. When prospects are geologically dependent, finding oil in one location might increase the chance of success in nearby locations. A dry hole may decrease the chance of success in adjacent prospects. Bickel and Smith (2006) addressed these informational relationships and calculated an optimal drilling sequence and its associated value. In practice, it takes time to interpret the drilling data and update the understanding about neighboring prospects, a span during which oil price variations may also change the economics of the upcoming wells. As a result, the optimal sequence of drilling decisions is a function of both the evolution of oil prices and geological dependencies. The compound uncertainty makes the valuation problem even more challenging. In this paper, we develop a framework for valuation of clusters of exploration opportunities where prospects are geologically dependent and uncertainty in oil prices is described as a mean-reverting stochastic process.

■ TE-17
Tuesday, 16:45-18:15 - 309A

Control theory and system dynamics

Stream: Control theory, system dynamics (contributed)
Contributed session
Chair: *Sakae Nagaoka*
Chair: *Suh-Wen Chiou*

1 - Robust signal control for urban traffic network with hazmat shipments
Suh-Wen Chiou

A robust bi-level signal control is developed for a road network. Since this problem is generally non-convex, a bounding strategy is developed to stabilize solutions and reduce relative gaps between iterations. The trade-offs between risk and travel costs are investigated. The proposed model exhibits advantage on mitigation of risk while incurred less cost as compared to others.

2 - Pump life monitoring and failure prediction based on vibration signal analysis in semiconductor manufacturing process
Youngji Yoo, Jun-Geol Baek

This paper presents a life monitoring and failure prediction method based on vibration signal analysis for a vacuum pump. In semiconductor manufacturing, the vacuum pump is mainly used to make the status in the chamber to vacuum. Failure of the vacuum pump can cause wasted time and cost by damaging the wafers being produced in the facility and performing unplanned maintenance. Therefore, it is important to monitor the condition of the pump and predict the failure in advance so that the pump is replaced or maintained before the failure occurs. The frequency data collected from the vibration sensor attached to the pump is used to detect a sudden failure of the pump. The amount of data is very large because the vibration sensor continuously collects the data during the process. Therefore, we extract the significant features of the frequency domain and time domain from the vibration signal data to reduce the size of data and remove noise. Based on the extracted features, we propose a health index to monitor pump life and predict failure. In this paper, the proposed method is tested and verified by using vibration sensor data collected from actual semiconductor process. The health index is expected to help engineers make better decisions about pump maintenance and replacement before breakdown.

3 - Condition-based maintenance and production planning
Michiel uit het Broek, Ruud Teunter

Many large plants like paper mills and refineries, commonly use so-called turnaround maintenance policies. In such policies, the entire system is shut down for a certain period and the whole system is maintained at once. Such policies allow for the maintenance activities to be clustered and planned long in advance, thereby minimizing system downtime as well as logistics costs, e.g., by reducing the need to stock many spare parts between turnarounds. However, the time between consecutive turnarounds is often large and machines may deteriorate faster then expected. In such situations, an interesting question is whether it can be profitable to reduce production rates in order to avoid the need for maintenance before a turnaround. The current maintenance literature typically assumes that machines always produce at its maximum production rate and that we therefore cannot influence the deterioration rate. However, there are many real life situations where we can adjust the production rates. For example, wind turbines can decelerate by adjusting the angle of the blades which results in lower production rates as well as reduced deterioration rates due to less vibration and lower heat production. We research the option to adjust production rates based on condition information. We conclude that the flexibility to operate with different production rates over time can decrease total maintenance costs while reducing the risk of a failure and improving the productivity of the system.

4 - Modeling an air traffic control difficulty index based on a distance in time-space domain of aircraft trajectory
Sakae Nagaoka, Mark Brown

Air traffic controllers handle air traffic to maintain a safe and orderly traffic flow. The capacity of airspace in air traffic management (ATM) systems depends on factors associated with difficulty such as workload and traffic complexity. To design airspace and operational scenarios for ATM systems, a method to estimate a difficulty index of air traffic control based on aircraft trajectory information is desired. Such an index can be designed by using information such as a geometrical distance in four-dimensional space. This presentation reviews a difficulty index proposed by the authors which firstly uses a purely geometrical viewpoint, and discusses some enhancements. We first describe the concepts of the equivalent relative distance of an aircraft pair and the temporal distance to a proximity situation, and then, determine the difficulty value for a pair of aircraft at a given instance using an evaluation function which consists of variables of distances derived from trajectory information. We also show application examples to trajectories on flat earth and spherical earth models. Finally, we briefly discuss several features and some problems of using this index in practical applications.

■ TE-18

Tuesday, 16:45-18:15 - 2101

Forecasting preferences for marketing applications

Stream: Data science and analytics (contributed)
Contributed session
Chair: *Gabrielle Gauthier Melançon*

1 - Learning consumer preferences for large-scale assortment optimization
Sanjay Dominik Jena, Andrea Lodi

The product assortment carried by a store directly impacts the sales and is among the most important decisions store managers have to make. Several mathematical models have been proposed to optimize assortments. Ranking-based choice models have been acknowledged for representing well high-dimensional product substitution effects, and therefore reflect consumer preferences in a reasonably realistic manner. In this work, we extend the concept of strictly ranked choice models to additionally allow for indifference for a subset of products on which the consumer does not have a strict preference. We show how we can learn such preference structures from large amounts of historical transaction and assortment data via column generation. The subproblems are efficiently solved using a growing decision tree that represents partially ranked preferences, enabling us to learn preferences and optimize assortments for thousands of products. While no transaction data may be available for new products, we further propose a method to integrate those products in assortments by learning their usefulness based on the underlying product characteristics. Computational experiments and case studies on artificially generated and real industrial retail data suggest a significant potential to increase profits when performing data-driven assortment optimization and provide useful insights on the importance of single products and their predicted impact on the sales of others.

2 - Assortment scoring for fashion in retail
Christian Hudon

Our project helps the assortment manager to decide which items will be part of the next assortment. An assortment is a subset of the items offered during a period in the department of a retail store, e.g. men shirt summer 2019.The scoring is a forecast of the performance of an item in an assortment based on the items attributes. Each assortment can have placeholders: a set of attributes for an item that doesn't exist yet. This partially defined item is then created by a fashion designer. Classical forecasting algorithms based on past sale history cannot be used due to the requirement to support placeholders. We offer a predictive measure of performance based on the item attributes and unit sales. When a new item is introduced, a measure if found based on the unit sales of items with some identical attributes. This measure can incorporate various data streams such as the past inventory quantity, special events and discounts. To minimize the impact of a potential prediction error and since the users are not statistical experts, we present the information in a way that shows only the outline of the forecast. We show multiple examples of the user experience used to attain this goal and the methods we use to make this information accessible to the user.

3 - Cognitive Predictive Models for Marketing Applications
Pavankumar Murali, Joe Zhou, Ta-Hsin Li, Pietro Mazzoleni

Financial institutions collect rich temporal data on their customers' behavior which include transactional data, interaction data, marketing data etc., in addition to static profile data. A key challenge in building predictive models is extracting the right set of features using raw temporal data that is high-dimensional, noisy and sparse. Deep learning (DL) techniques have gained popularity recently in their ability to identify statistically significant temporal behavior features. An area of focus is the development of interpretable deep learning models that are capable of providing individual customer-level reasons for a predicted outcome. In this talk, we discuss interpretable DL techniques we have built for marketing applications in the financial services area and compare their performance with a logistic regression model.

4 - Preference-based customer segmentation for assortment planning
Gabrielle Gauthier Melançon

Every season, retailers must decide what products to include in their stores. For fashion retailers, this task is particularly complex, since they often carry new products for which they must use their intuition to determine how customers are going to react. Since a business typically have a large amount of customers, it is not achievable for a retailer to understand all of their customers individually. At JDA, we developed a preference-based customer segmentation process that can help to solve this problem. To do this, we analyze product attributes to discover customers' motivation and preferences. We then look for patterns and similarities between different purchases and group shoppers accordingly. This process has been iteratively developed with the help of multiple large-scale retailers. It has proven to bring insights that sometimes validate merchants' intuition, but that also uncovers new point of views on the business.

■ TE-19

Tuesday, 16:45-18:15 - 2102AB

Stochastic lot-sizing

Stream: Lot-sizing and related topics
Invited session
Chair: *M. Karimi-Nasab*

1 - Multi-period production planning by Shapley value model with constraints
Nobuyuki Ueno, Koji Okuhara

We present a multi-period production planning problem under the framework of coalitional game theory. The problem is to determine the production volume for each period subject to both total demand risk which is defined as the characteristic function AVaR (Average Value-at-Risk) and linear production constraints. The conventional Shapley value is employed to evaluate the allocated demand risk for each period in the case that there exist no constraints. Since, in general, Shapley value model with constraints obtains no feasible solution, we propose an available solution model based on Shapley value model.

In the model, individual rationality is relaxed and it is formulated as a quadratic programming of which the objective function is the total penalty of individual rationality. We show numerical illustrations. The proposed model can make efficiently a production manager forecasting the demand risk and the production volume for each period under the confidence level in a predefined time horizon.

2 - Stochastic and deterministic lot-sizing problems with different evaluation frameworks
Dariush Tavaghof-Gigloo, Stefan Minner

We present a mixed integer linear programming (MILP) approach to integrate dynamic safety stock planning into the different lot-sizing problems. We consider a base stock policy with different service measures or a cost model. We implement state-of-the-art linearization techniques for the non-linear first-order loss function. We conduct an extensive full factorial numerical study, by taking input factors like the minimum production quantities, capacity limitations, demand variations, and etc. into account, to reveal the behavior of the stochastic and the deterministic lot-sizing problems under the rolling planning horizon and the fixed (open loop) planning horizon frameworks.

3 - Production scheduling with perishable inventories of limited lifespan
Mehdi Karimi-Nasab

In this research, a number of products should be produced over a number of planning periods. Also, in each period, there is limited available time. In addition, once a unit of item type k is produced in period t0, it can be considered with 100% certainty in the warehouse as healthy inventory till the next tlk-1 periods (i.e. in periods t0, t0+1,...,t0+tlk-1). On the other hand, such product is certainly perished tuk+1 periods after its production. But, such a product can be either healthy with probability θk in period t, where t0+tlk t t0+tuk. Such thresholds are determined by either health regulations or statistical estimates. In this research, θk follows from a general discrete distribution. In this environment, product life time is bounded and has two phases: healthy phase, and probabilistically-healthy phase. Such products are very common in real life and examples could be canned foods, shampoos, and so on. The production manager wants to minimize the total expected costs while having (1-α)100% confidence level of the feasibility of such a production plan. The problem is formulated as a mixed integer nonlinear program. Then, some solution approaches are devised to solve it.

4 - Analysis of the effect of the distribution parameters on the optimal inventory policy and performance measures
Boualem Rabta, Gerald Reiner

Inventory models can be very complex. They may contain a large number of parameters of which many can be stochastic (e.g. demand). Their performance measures are generally not available in closed form. For instance, the stationary distribution of the position inventory level in the (s,S) inventory model is given with respect to the renewal function of the demand distribution. It is very difficult to calculate for general probability distribution. Additionally, most of the parameters, particularly the demand distribution, are estimated from empirical data by means of statistical methods. Hence, it is useful to understand which and how parameters of the demand distribution can affect the optimal policy. In this work, we analyze the effect of the demand distribution parameters on the optimal inventory policy and performance measures. In particular, we consider small changes that may arise from the approximation of the demand distribution and/or the estimation of its parameters by statistical methods. Along with the mean and the variance of the demand, we also consider the effect of higher moments (particularly, skewness and kurtosis). To achieve our goal, we construct a design of experiments to allow the variation of multiple parameters at ones and the possibility to identify their interactions. We aim to determine the influential factors and interactions by understanding how the changes in those factors individually and jointly affect the output performance measures.

■ TE-20
Tuesday, 16:45-18:15 - 2103

Applications of risk-averse optimization

Stream: Stochastic optimization
Invited session
Chair: Daniel Jiang

1 - Stochastic optimization with risk parity
Alexander Vinel

The concept of risk parity has recently attracted a considerable attention in the area of financial portfolio management. This approach is aimed at explicitly enforcing diversification in the portfolio by ensuring that each asset is equally contributing to the total variance. In this talk, we consider risk parity (RP) idea in conjunction with modern risk-averse stochastic optimization, study a generalized RP model and propose a combined two-stage risk-reward-diversification framework. We also present results of numerical case studies outlining the performance of CVaR-based risk parity in decision making problems with real-life data under highly heavy-tailed distributions of losses.

2 - Managaing shutdown risk in commodity and energy production
Alessio Trivella, Selvaprabu Nadarajah, Stein-Erik Fleten, Denis Mazieres, David Pisinger

Commodity and energy production assets face the risk of having to permanently shut down when operating in an uncertain environment, for instance, due to fluctuations in input/output prices and exchange rates. In this paper, we formulate a new shutdown risk-averse Markov decision process (MDP) to balance the asset market value and shutdown risk. We adapt the regress-later least squares Monte Carlo method to compute heuristic risk-averse operating policies for our high dimensional MDP. We apply this approach to a realistic aluminium smelter application with mothballing and shutdown flexibility. Our numerical results show that our shutdown risk-averse policy outperforms CVaR-based policies, providing more efficient trade-offs between asset value and shutdown risk. Further, we compare the reductions in shutdown risk when employing our risk-averse operating policies and using long-term forward contracts for procuring/selling inputs/outputs, and find that the former operational hedging strategy outperforms the latter financial hedging strategy. These findings are potentially relevant beyond aluminium production to the management of shutdown risk in other commodity and energy production assets.

3 - A spectrum of risk-averse optimal policies for electric vehicle charging
Daniel Jiang, Warren Powell

We consider the sequential decision problem faced by the manager of an electric vehicle (EV) charging station and present new methodology that generates a "spectrum" of risk-averse policies under dynamic risk measures. We investigate the connection to the more traditional risk vs. reward framework.

■ TE-21
Tuesday, 16:45-18:15 - 2104A

MADM principles 4

Stream: Multiple criteria decision analysis
Invited session
Chair: Hei Chia Wang
Chair: Pin-Ju Juan

1 - Knowledge management strategy of semantic web service repository
Hei Chia Wang, Chi-Fai Pao

In this work, we present a web service matchmaking method - Hybrid-IOND, a novel approach for web service retrieval based on the evaluation of similarity between web service interfaces and semantic ontology matchmaking. Our approach assumes that the Web service interfaces are defined with OWL Web Ontology Language for Services (OWL-S). The algorithm combines the logic-based reasoning and information retrieval methods on service matchmaking, and we also consider adding service name and servicing description to enhance the accuracy of service matchmaking for supporting the process of web service discovery and automated web service composition. The experiments results show that the proposed method not only is useful when we need to find a web service for a specific request, but also has better performance than other service methods.

2 - New maritime paradise: Exploring the selecting factors regarding cross-strait senior tourists in cruise travel
Wen-Yu Chen

Cruise travel has been growing swiftly and is also the newest industry in the global tourism market; it also demonstrates great potential in aspect of global economic development. Meanwhile, Asia is a fast-emerging market, and many cruise lines are very keen at expanding in this region. Moreover, the senior-traveler market, one of the fastest booming market segments in the global tourism industry, has particularly become pivotal in its significance. When it comes to many Asian countries such as Taiwan, Japan, South Korea, Hong Kong, and China, etc., where group package tour (GPT) is regraded as one of the main modes of outbound travel, cruise travel has become more and more popular amid majority of the Asian travellers, including the senior group package tourists. Regardless the growing significance related to the senior-group-package tourists of cruise travel, obviously, there is deficiency concerning how they react to the selecting factors when choosing a cruise tour. The present research will combine qualitative (literature review, in-depth interviews, and six focus groups between Taiwan and Mainland China) and quantitative (questionnaire) methods to explore the selecting factors of senior tourists. Above all, the results generated from this study substantially offer some explicit references concerning senior tourists' selecting factors. In the meantime, recommendations for future research and managerial implication are also provided.

3 - Measuring location selection factors for hostels
Pin-Ju Juan, Peng-Yu Juan, Yi-Shan Chen

This study presents a framework of issues to analyze Porter's (1990) Diamond model, and develops factors for determining the optimality of a hostel location using Delphi method and the Decision-making Trial and Evaluation Laboratory (DEMATEL) approach. A panel of 13 experts from various backgrounds, including academia, government and business, provided input for the selection of location factors. Following three discussions, panel members reached consensus and selected the following set of 31 factors for optimizing location selection for hostels. This study also provides direction for applying the proposed model and suggestions for future research.

■ TE-22

Tuesday, 16:45-18:15 - 2104B

Learning in constraint programming

Stream: Constraint programming
Invited session
Chair: Claude-Guy Quimper

1 - Learning parameters for the sequence constraint from solutions
Émilie Picard-Cantin, Mathieu Bouchard, Claude-Guy Quimper, Jason Sweeney

Accurate mathematical modeling requires a specific and complex training process and a lot of modeling experience as there are as many models as there are problems. This is why modeling automation has become a popular field of study. We propose an approach that, based on machine learning, analyzes given positive examples (solutions) for a known global constraint and determines which set of parameters better explains these examples using Markov chains. It is a statistical approach that detects the parameters of multiple global constraints such as Among and Sequence, common constraints used in timetabling. The algorithm can be applied to both soft and hard constraints.

2 - Counting weighted spanning trees to solve constrained minimum spanning tree problems
Gilles Pesant, Antoine Delaite

Building on previous work about counting the number of spanning trees of an unweighted graph, we consider the case of edge- weighted graphs. We present a generalization of the former result to compute in pseudo-polynomial time the exact number of spanning trees of any given weight, and in particular the number of minimum spanning trees. We derive two ways to compute solution densities, one of them ex- hibiting a polynomial time complexity. These solution densities of individual edges of the graph can be used to sample weighted spanning trees uniformly at random and, in the context of constraint programming, to achieve domain consistency on the binary edge variables and, more im- portantly, to guide search through counting-based branching heuristics. We exemplify our contribution using constrained minimum spanning tree problems.

3 - A posteriori evaluation of counting-based branching heuristics in constraint programming using data mining
Samuel Gagnon, Gilles Pesant

Couting-Based Search (CBS) is used for branching in constraint programming and represents a family of heuristics based on marginal distributions of solutions in individual constraints. A relatively simple member of this family, maxSD, works well in practice on a number of combinatorial problems but are there better ways to exploit such information? We try to answer this question by using machine learning techniques on a large set of empirical data.

4 - Generalizing the edge-finder rule for the cumulative constraint
Vincent Gingras, Claude-Guy Quimper

Scheduling problems are omnipresent in the domain of operations research. Applications in manufacturing are good examples of such problems as manufacturing operations must be scheduled on a shared production line, or resource. In recent years, constraint programming have had great success in solving such problems. Many filtering rules and algorithms have been presented in the literature over the course of the years for the scheduling constraints. In order to be executed in polynomial time, these algorithms are based on a relaxation of the problem defined as fully-elastic. In this talk, we present a novel generalization of two known filtering rules: the Overload Checking and the Edge-Finding. Both rules filter the Cumulative constraint based on the computation of the earliest completion time of a set of tasks. We illustrate the filtering power that can be achieved with this relaxation by presenting two novel filtering algorithms enforcing these newly generalized rules with a stronger energetic relaxation of the problem. The algorithms utilize a novel data structure, that we call the resource utilization profile, and that encodes the resource utilization over time. Experiments show that these algorithms are competitive with the state-of-the-art algorithms, by doing a greater filtering and having a faster runtime.

■ TE-23

Tuesday, 16:45-18:15 - 2105

Real-time planning

Stream: Optimization for public transport
Invited session
Chair: *Ángel Marín*
Chair: *Esteve Codina*
Chair: *Ricardo Garcia-Rodenas*
Chair: *Luis Cadarso*

1 - Marketing automation for the railway industry
Maria Luz Lopez, Ricardo Garcia-Rodenas, Jose Carlos Garcia Garcia

Nowadays, railway control and planning methods incorporate robustness and recoverability as strategies to improve the fault tolerance of the system. However, disruptions continue to appear in the railway network causing delays, cancellations of trains, etc. A palliative strategy is to compensate passengers, which suffer these adverse situations. A set of commercial actions can be provided free of charge to these passengers in order to improve their satisfaction. We propose an expert system to recommend these commercial actions to the passengers. The system consists of two stages. At the first stage, a taxonomy of passengers is built on the basis of two KPIs (key performance indicators). The KPI1 is the value of the customer to the railway operator and the KPI2 is the satisfaction of the passenger. Both KPIs define a set of patterns of users. A multiobjective linear approach allows a master plan for the distribution of commercial actions among the set of patterns of passengers to be built. The second stage consists of the assignment of these commercial actions to the individuals in real time. If a passenger buys a ticket via an online sales channel then the system detects the characteristics of this customer. A set of rules, the master plan and the current inventory of actions allows the expert system to provide a specific commercial action if it is appropriate.

2 - An investigation into targeted dynamic control for real-time traffic management of large railway networks
Taha Ghasempour, David Kirkwood, Fang Xu, Gemma Nicholson, Benjamin Heydecker, Taku Fujiyama

Railway operations are prone to disturbances that can rapidly propagate through large networks, causing delays and poor performance. Deploying automated rescheduling tools has shown the potential to limit such undesirable outcomes. Many mathematical algorithms for these tools have been described, but further attention should be paid to methods of implementation and their effects on operations, which are not yet well understood. Furthermore, the computational time for real-time rescheduling of railway operations depends heavily on the magnitude and frequency of delay instances, and will increase considerably based on the size of the area of the network that is being controlled. This makes the size of the selected control area particularly important for an effective implementation. This paper investigates the effects of employing a hierarchical optimisation approach which controls the motion of trains by real-time management of train sequences and speed profiles for individual trains. It is applied to a large section of the East Coast Main Line railway in the UK in a realistic simulation environment by deploying the method with three distinct strategies. These are: i) controlling a small, but critical part (i.e. a junction) on the study network; ii) controlling several critical parts independently from one another; and iii) controlling all of the study network jointly in a centralised manner. The effect of these strategies on the performance of the network is then evaluated.

3 - Rescheduling a train service plan accounting for energy consumption and passenger compensation policy in case of disruptions
Luis Cadarso, Ricardo Garcia-Rodenas, Ángel Marín

In a railway network, incidents may cause traffic to deviate from the planned operations making impossible to operate the schedule as it was planned. In such a situation the operator needs to adjust the schedule in order to get back to the original schedules. A train operator may have the policy of economically compensating (e.g., refunding ticket fare) passengers when they incur in delays. Compensation levels usually depend in the amount of delay. Therefore, it is important to have a smart way of deciding whether to speed up trains in order to absorb delays, i.e., increasing energy consumption, or to compensate passengers. In this talk a mathematical model which decides on the speed profile while considering passenger use is presented. The model decides on the optimal sequence of operating regimes and the switching points between them for a range of different circumstances and train types all while considering delays and passenger compensation policies applied by the train operator. The objective of this paper is to minimize both energy consumed and incurred compensation to passengers. Constraints on traction and braking forces, on train velocity, on forces caused by vertical and horizontal track profile, and on passenger compensation policy are considered. Computational tests on realistic problem instances of the Spanish rail operator RENFE are reported. The proposed approach is able to find solutions with a very good balance between various managerial goals.

4 - A railway rapid transit network design model with variable demand sensitive to the disruptions
Esteve Codina, Francesc López-Ramos, Ángel Marín

In this communication, a recoverable robust network design model (RRND) is proposed. The RRND considers a finite set of disruption scenarios arising from infrastructure malfunction or rolling stock failures. These failures are represented as disruption probabilities depending on the amount of services, the structural factors of the design itself and the level of maintenance of the infraestructure. An additional factor considered by the model is the uncertainty in the demand due to the following reasons: 1) The sensitivity of public transport users to situations of disruption, 2) The presence of alternative modes of transport and, 3) the possiblity to cancel travelling by a fraction of the demand. The model is formulated as a bi-level structure and solved using a heuristic solution method. Reported results for small to medium-sized networks shows the computational viability of the model.

■ TE-24

Tuesday, 16:45-18:15 - 301A

Machine learning and optimization for homecare

Stream: CORS SIG on healthcare
Invited session
Chair: *Nadia Lahrichi*
Chair: *Louis-Martin Rousseau*

1 - An ALNS for the home health care routing and scheduling problem
Florian Grenouilleau, Nadia Lahrichi, Louis-Martin Rousseau

The Home Health Care Routing and Scheduling Problem consists of scheduling, over a week, a given set of home visits and deciding which health resource will be used to perform each visit in which sequence. This problem can be seen as a mix between an assignment problem, with the visit allocation decision, and a vehicle routing problem with time windows for the scheduling part. In our study, we try to take into account a maximum of practical constraints. These constraints are partly linked to the assignment component of the problem, such as assuring the qualifications and availabilities of each nurse for each visit. We also consider, for the scheduling part, the time-dependent aspect of the travel times and the maximum amount of work hours per nurse over the week and over each workday. To solve this problem, we use a well-known method calls Adaptive Large Neighborhood Search (ALNS) which, starting from an initial solution, iteratively reconstruct some parts of this solution and try to produce a better one. To do so, we have developed problem-specific ALNS' destroy and repair operators coupled with classic ones. To test our method, we have used real data provided by the Alayacare company, a Canadian company which has created software for the home health care management. The results show that our metaheuristic permits to dramatically improve the Alayacare's solutions, by reducing the travel time by 30% and improving the patient-nurse fidelity by more than 6%.

2 - Dynamic scheduling of home care patients to medical providers

Andre Augusto Cire, Adam Diamant

Home care aims at providing personalized medical care and social support to patients within their own home. It allows patients to avoid unnecessary hospital costs and either prevents or postpones long-term institutionalization. In this work we propose a dynamic scheduling framework to assist in the assignment of patients to home care practitioners (or HPs). An HP attends to the individual for the entirety of their care (continuity of care requirement) and must travel to their homes in order to serve them. We formulate the assignment of patients to HPs as a discrete-time Markov decision process (MDP). Due to the curse of dimensionality and the complex underlying combinatorial structure of the problem, we propose a one-step policy improvement heuristic that builds upon the agencies existing assignment strategy. Specifically, we apply machine-learning techniques to learn different probabilistic policies from historical data, and formulate the one-step improvement problem as an exponentially-sized mathematical programming model. Such a model can be solved using a Benders decomposition approach that simultaneously provides upper and lower bounds at each iteration. We test the quality of our solution methodology with data from a Canadian home health care provider to assess the service improvement as compared to their existing policies.

3 - Machine learning algorithms in home care services

Violaine Mongeau-Pérusse, Nadia Lahrichi, Louis-Martin Rousseau

In the province of Québec, currently 18 % of the population is above 65 years old and this number keeps growing (Canada Statistic, 2016). With this increase, the cost and demand for hospitalization is rising rapidly. It is important to find alternative solutions to treat more people at home, for many health conditions. Therefore, homecare agencies are facing increasing challenges to be more and more efficient. In this project, we will investigate the case of wound care and chronic disease surveillance at home. The first part of this presentation will focus on the use of big data in the prediction of the duration of the wound healing. Many machine learning algorithms are tested to determine the model with the best prediction. These models include logistic regression and random forests. The second part of the presentation focuses on a telemonitoring program in home health care and the prediction framework for these patients. Maxout neural networks are used to predict home telemonitoring patient's adverse events.

4 - Vehicle routing problems with synchronized visits and stochastic/time-dependent travel and service times: applications in healthcare

Seyed Hossein Hashemi Doulabi, Louis-Martin Rousseau, Gilles Pesant

This paper, for the first time, studies vehicle routing problems with synchronized visits (VRPS) where travel and service times are stochastic/time-dependent. We formulate VRPS with stochastic times as a two-stage stochastic programming model with integer variables in both stages. We prove that the integrality constraints on second-stage variables are trivial, and therefore we can apply the L-shaped algorithm and its branch-and-cut implementation to solve the problem. We enhance the model by developing valid inequalities and a lower bounding functional. We analyze subproblems of the L-shaped algorithm and devise a solution method for them that is much faster than standard linear programming algorithms. Moreover, we extend our model to formulate VRPS with time-dependent travel and service times. In addition to considering a home-healthcare scheduling problem, we introduce an operating rooms scheduling problem with stochastic durations as a novel application of VRPS. Computational results demonstrate the effectiveness of the proposed algorithms.

■ TE-25

Tuesday, 16:45-18:15 - 301B

Game theory and optimization for health and life sciences 2

Stream: Optimization, analytics and game theory for health and life sciences

Invited session

Chair: *Gerhard-Wilhelm Weber*

Chair: *Sadia Samar Ali*

Chair: *Qi Cao*

1 - Visual interface of classifier system for psychiatric patients

Edwin Montes-Orozco, Javier Ramirez-Rodriguez, Roman Anselmo Mora-Gutiérrez, Carlos Cruz Ulloa, Sergio de-los-Cobos-Silva, Eric Alfredo Rincón-García, Miguel Angel Gutierrez, Antonin Ponsich, Pedro Lara-Velazquez

In this work, a visual interface for a classifier system based on a set of rules, is presented. This system, is able to identify the psychiatric disorder of single one, with based on information of five biological constants, which are taken in phase REM. The classifier system compared results generated both a model obtained for a metaheuristic hybrid denoted as GP-MMC (Method of the Musical Composition and the Genetic Programming) and other model produced by linear regression. The numerical results show that the it system is reliable to correctly classify an individual with a percentage of certainty between 70% to 80%

2 - Controlling mass-casualty flow for emergency healthcare: A simulation analysis

Mohsin Nasir Jat, Raza Ali Rafique, Muhammad Shakeel Sadiq Jajja, Sanna Ullah

An engagement of multiple medical facilities in response to a mass-casualty incident implicates the issue of an efficient distribution of casualties within the facilities. We seek to explore this issue through a discrete event simulation analysis of a terrorist bomb attack instance in a major city of Pakistan—a country that has experienced frequent terrorism incidents in the recent past. The work compares three response approaches. The first involves directing all of the casualties towards the nearest hospital. When the nearest hospital's capacity is exhausted, the casualties are redirected to the other hospitals in the system. This standard approach essentially places the control center role at the nearest hospital. The second approach involves directing some set proportions of the casualties towards the hospitals. In the third approach, the casualties are directed towards the nearest hospital until some capacity threshold level is reached, triggering the diversion of the traffic to the other hospitals. The latter two approaches require the casualty flow control at the incident location. Though the analysis is based on a terrorism related incident, the insights can be relevant for any type of urban disasters resulting in instantaneous mass-casualties, e.g., transportation and industrial accidents.

3 - Population-based allocation of limited CRC screening resources

Abdelhalim Hiassat, Fatih Safa Erenay, Osman Ozaltin

Colorectal cancer (CRC) can be early-detected, and even prevented, by undergoing periodic cancer screenings via colonoscopy. Current guidelines are based on existing medical evidence, and do not consider i) all possible alternative screening policies, and ii) the limited capacity for screening and economic feasibility. We consider the problem of allocating limited colonoscopy resources for CRC screening and surveillance among different patient groups based on age, CRC history, and other risk factors. We develop a mixed integer program that maximizes the quality adjusted life years for a given patient population considering the population's demographics, CRC progression dynamics, and relevant constraints on system capacity and screening program effectiveness.

4 - Value of information analysis using non-parametric regression models: A case study in heart failure disease management

Qi Cao, Erik Buskens, Maarten Postma, Douwe Postmus

In health care, decision analytic models are frequently used to perform long-term, comparative evaluations of the cost-effectiveness of alternative treatment regimens. As knowledge regarding the exact values of the model parameters is usually limited, probabilistic sensitivity analysis (PSA) is generally conducted to propagate the uncertainty in the model inputs into uncertainty on the modelled outcomes. Analysis of uncertainty thus contributes to inform rational policy decisions. Recently, in addition to "traditional" cost-effectiveness acceptability curves, value of information (VOI) analysis has become more broadly used as a tool to present the results of a PSA. Such a VOI-analysis calculates a bounded value (expected value of partial perfect information, also known as EVPPI) to indicate which subset of model parameters are the main drivers of decision uncertainty, and subsequently investigates the added value of conducting future research to obtain better estimates of these specific parameters. As it is computationally intensive to calculate EVPPI analytically, a recent review concluded that a non-parametric regression approach may be the most efficient way to approximate the EVPPI. In this study, we will apply this approach to a previously conducted model-based economic evaluation on heart failure disease management. The comparators considered were a conventional nurse-led management program and an alternative strategy using a novel point-of-care testing device.

■ TE-26

Tuesday, 16:45-18:15 - 302A

Equilibrium problems in energy 2

Stream: Equilibrium problems in energy
Invited session

Chair: *Kerstin Daechert*
Chair: *Tim Felling*

1 - A bicriteria perspective on an L-penalty approach for solving MPECs

Kerstin Daechert, Sauleh Siddiqui, Javier Saez-Gallego, Steven Gabriel, Juan Morales

We focus on complementarity problems as a special case of MPECs. Even if all functions involved are linear the complementarity condition is non-convex and makes the problem challenging, in general. Several approaches exist in the literature that reformulate the complementarity condition, e.g., disjunctive constraints or Schur's decomposition. Recently also an L-penalty method was proposed in Siddiqui and Gabriel (2012). In this talk we consider the latter approach from a bicriteria perspective. For linear problems we can easily indicate the solutions of the L-penalty formulation for all positive values of L. We can interpret parameter L as the trade-off between the original objective and the L-penalty term. The larger L the more emphasis is given to the penalty term. We prove a new theorem which shows conditions under which this L-penalty approach finds a solution satisfying complementarity for sufficiently large L. We also demonstrate limitations of the proposed L-penalty formulation by indicating examples not satisfying these conditions for which a complementarity solution exists but can not be generated for any positive L.

2 - A robust approach to transmission constraints in zonal electricity markets

Tim Felling, Björn Felten, Christoph Weber

In order to solve equilibrium problems in electricity the first-best solution in literature often refers to nodal pricing. Nevertheless, an improved zonal pricing system, Flow-Based Market Coupling (FLB-MC), is online for the Central Western European (CWE) region since May 2015. For this second-best market coupling approach, nodal injections are estimated by so-called generation shift keys (GSKs). This approximation makes FLB-MC a robust optimization problem, if uncertainties in GSKs are considered properly. This affects capacity margins and thus reduces the solution space. Therefore the flow reliability margin (FRM), a security margin on lines, arising from GSK uncertainty is derived analytically and assessed numerically. The necessary size of FRM, that has to be foreseen in order to prevent re-dispatch and countertrading, is explained. By deriving FRMs as a function of number of price zones in a realworld system the conclusion on the convergence of FRMs towards the nodal setup can be drawn. In a nodal setup FRMs are non-existent as there are no GSK uncertainties. In conclusion, this paper contributes to the improved understanding of advances from NTC-based MC to FLB-MC without ignoring its shortcomings against the first-best solution of nodal pricing. New insights that have not been addressed sufficiently and in a combined manner in recent literature are developed notably GSK uncertainties and the assessment of FRM depending on the number of price zones.

3 - Strategic generation investment using a stochastic rolling-horizon MPEC approach and adaptive risk management

Thomas Kallabis, Steven Gabriel

Investments in power generation assets are multi-year projects with high costs and multi-decade lifetimes. Since market circumstances can significantly change over time, investments into such assets are risky and require structured decision-support systems. Investment decisions and dispatch in electricity spot markets are connected, thus requiring anticipation of expected market outcomes. This strategic situation can be described as a bilevel optimization model. At the upper level, an investor decides on investments while anticipating the market results. At the lower level, a market operator maximizes revenue given consumer demand and installed generation assets as well as producer price bids. In this talk, we reformulate this problem into a Mathematical Program with Equilibrium Constraints (MPEC). We extend this model to include a dynamic rolling-horizon optimization. This structure splits the investment process into multiple stages, allowing the modification of wait-and-see decisions. This is a realistic representation of actors making their decision under imperfect information. Furthermore, we model an endogenous learning algorithm that allows updating risk-aversion parameters. These two extensions allow us to investigate the success of learning algorithms in strategic investment decisions. Lastly, the rolling-horizon formulation also has computational advantages over a perfect foresight and we provide supporting numerical results to this point.

4 - Flow-based market coupling in the European electricity market

Endre Bjorndal, Mette Bjørndal, Hong Cai

In May 2015, the Flow-Based Market Coupling (FBMC) model replaced the Available Transfer Capacity (ATC) model in Central Western Europe to determine the power transfer among countries (price areas). The FBMC model aims to enhance market integration and to better monitor the physical power flow. The FBMC model is expected to lead to increased social welfare in the day-ahead market and more frequent price convergence between different market zones. This paper gives a discussion of the mathematical formulation of the FBMC model and the procedures of market clearing. We examine the FBMC model in two test systems and show the difficulties in implementing the model in practice. We find that a higher social surplus can come at the cost of more re-dispatching. We also find that the FBMC model might fail to relieve network congestion and to better utilize the resources even when compared to the ATC model.

■ TE-27

Tuesday, 16:45-18:15 - 302B

Behavioural issues in environmental-decision making 2

Stream: Behavioural OR
Invited session
Chair: *Judit Lienert*

1 - Designing decision processes to overcome barriers to sustainable water systems

Lisa Scholten

In 1997, Mingers and Brocklesby suggested to classify problem structuring methodologies by their ability to support deliberation and analysis concerning the personal, social, and material aspects underlying complex problems by a phased decision support intervention. This should build the basis for multimethodology designs (MMD) that focus on those aspects needing particular attention. How to identify these aspects, however, is not clear. Since then, a range of MMDs have been used, but reflection, reporting and evaluation of their design is missing. That hinders uptake by those organizations that need to achieve change. A field with a pressing need for change is water management. Although promising solutions are available, the current socio-technical system usually prevails due to a plethora of possible barriers. Many barriers are related to personal, social, or material aspects that affect decision making. If it were possible to identify adverse preconditions, could this be used to conceive MMDs that are likely to overcome these barriers? I will present results from recent work, where colleagues and I developed an approach to identify adverse preconditions by a combined analysis of the partaking actors, their collaboration networks, and their decision-making processes. Based on this, I will discuss challenges in defining suitable MMDs and explore possible ways of complementing Mingers and Brocklesby's framework to support design and evaluation of mixed MMDs in practice.

2 - Behavioural aspects of decision making in energy systems - A selection of current topics

Valentin Bertsch

To combat climate change, greenhouse gas emissions need to be reduced globally. The decarbonisation of the energy system is an important prerequisite in this context. While the EU plans to decarbonise the energy system mainly by energy efficiency and expanding renewable energy sources (RES), other countries focus on nuclear or carbon capture and storage technologies. In either case, energy systems around the world are in a phase of transition and change requiring significant investments in various technologies. On the supply side, this involves investments in RES and non-RES generation technologies as well as the grid-based infrastructure. On the demand side, this may involve the adoption and use of more efficient appliances including a move to heat pumps or electric vehicles for instance, but also the adoption of new tariffs and pricing mechanisms. However, experiences show that citizens may object to the construction of new energy infrastructure in their localities and the consumer uptake of new technologies stays behind expectations. These observations underline that engineering optimisation or econometric methods alone are not sufficient to understand decisions and provide adequate decision support. This paper provides an overview of interdependencies and interactions between the different actors in energy systems and presents a selection of current topics focussing on behavioural factors influencing consumer acceptance, adoption and use of new technologies and tariffs.

3 - Energy use feedback: A behavioural OR approach toward better decisions and more efficient energy behaviours

Marta Lopes, Carlos Henggeler Antunes, Hermano Bernardo, Humberto Jorge

End-users' behaviour is presently recognised as a key factor in promoting energy efficiency and is also gaining special relevance during the on-going transition to smart grids. In this context, feedback on energy consumption is a vital tool to materialise energy use and support end-users' decision making in energy related issues. Although research has explored the influence of different types of feedback on energy use (e.g., historical, normative, disaggregated consumption, using billing and home energy monitors), further and systematic investigation is required to establish the best type of feedback to provide to end-users to induce more efficient behaviours. These issues are particularly relevant in more complex contexts such as the evolution to smart grids. As an emerging discipline aiming to make better use of models and address behavioural issues that influence decision making in real-life contexts, Behavioural Operations Research (BOR) is used to develop controlled systematic studies on energy use feedback. So far, BOR applications in energy efficiency have mainly used problem structuring methods to assist the development of multicriteria decision support approaches. This work presents an analysis of feedback information to end-users in smart grid contexts using a behavioural lens, particularly by determining which end-users' behaviours are influenced and how they are enacted by feedback processes to produce best energy use practices.

4 - Are all proposed objectives useful in environmental decision-making?

Judit Lienert, Valerie Belton, Fridolin Haag, Jyri Mustajoki, Mika Marttunen

In complex environmental decisions, many interests need to be satisfied. In Multi-Criteria Decision Analysis (MCDA), these can be included as objectives and attributes. It is widely acknowledged that this problem structuring step is of crucial importance for later phases of the MCDA. The decision analysis literature gives general advice on how to construct objectives hierarchies (e.g. complete, concise, non-redundant), but there is an astonishing lack of recent research and guidelines to support this process in practice. For instance, it is often unclear, when one should stop adding objectives. Our experience suggests that objectives hierarchies may reach an alarming size. This was supported by a meta-analysis of 61 environmental and energy MCDA cases (Marttunen et al., subm. a). Too many details can distract attention from the most important issues, or lead to systematic biases in later preference elicitation. Our research also indicates that the symmetry of the hierarchy can affect the weights given. We present a novel framework to support the systematic development of concise, well-structured objectives hierarchies (Marttunen et al., subm. b). We propose using both qualitative (means-ends networks, relevancy analysis) and quantitative methods (correlation analyses, PCA, sensitivity analyses) in an early phase of MCDA to build better hierarchies. We apply these methods ex-post in two environmental cases and discuss their advantages and disadvantages.

■ TE-28

Tuesday, 16:45-18:15 - 303A

Medicine, computational biology and bioinformatics

Stream: Computational biology, bioinformatics and medicine
Invited session
Chair: *Jacek Blazewicz*
Chair: *Anissa Frini*

1 - Influential factors analysis of the needs on stroke patients

Changzheng He, Xiaozhou He, Yuanyuan Zhuang

The aim of this paper is to identify the influential factors of the needs of the stroke patient in various dimensions, thereby providing the scientific basis for the implementation of care interventions and promoting the speedy recovery of patients. A questionnaire is designed to collect feedback from inpatients. A convenience sample of 640 stroke patients or their relatives is recruited from the neuropathy and rehabilitation wards of tertiary hospitals in southwestern China. Descriptive statistics are calculated from the demographic information. And Pearson correlations and multiple stepwise regressions are used to examine the nature and degree of the relationships between factors and domain-specific needs. This study found that personality is an important influencing factor on needs of the stroke patient. For psychological needs, persistence and self-directedness are the most significant predictors; for physiological needs, novelty seeking is the most significant factor; and for safety needs, novelty seeking and cooperation are the most significant factors. Our ndings indicate that there are multiple factors that influence the needs of stroke patients. Personality features strongly influence needs of stroke patients. Other factors such as age, annual income, education, social support and ADL also influence needs of patients.

2 - Assessing and improving trauma outcomes prediction models

Fatima Almaghrabi, Dong-Ling Xu, Jian-Bo Yang

Background and Motivation: Trauma is a major public health issue and a major cause of mortality and disability worldwide. In England and Wales, for example, there were 17,201 injury-related deaths, in 2010. Due to their importance in patient care, trauma outcome prediction models are required to be accurate and reliable. Many researchers have investigated different trauma prediction models; however, only a few have conducted comparative analyses to determine the best performing algorithms for this purpose. This research aims to identify the most accurate tools for building a prediction model and increasing model accuracy through Identifying which algorithms have the highest classification accuracy in predicting trauma outcome. Methodology: This research considers the prediction variables based on the model proposed by Bouamra et al. (2015). This proposed research applies that model to a classification problem. The results of some ML algorithms, such as Support vector machine (SVM), decision tree (DT) in addition to ER rule-based classifier results are compared to the logistic regression algorithm results presented in Bouamra et al.'s (2015) paper. Results: SVM and DT algorithms were applied with a cross validation method. The preliminary results of the research show that SVM model outperforms DT by a small difference in accuracy. Expected Contribution: The results should be of interest not only to the health care community but also to the machine learning community.

3 - A sorting multi-criteria approach for evaluating polypharmacy quality

Anissa Frini, Caroline Sirois, Marie-Laure Laroche

Although many older individuals are exposed to polypharmacy, there is no clear definition of what are appropriate and inappropriate polypharmacy. This article proposes an original approach for classifying polypharmacy using multi-criteria sorting methods. We provide clinicians with a list of drugs potentially involved in treating an older patient suffering from three diseases (diabetes, chronic obstructive pulmonary disease and heart failure). Clinicians have to express their opinion on a 5-point Likert scale and may hesitate between two or more responses. While evaluating each drug, they assess the risks, benefits and impacts on quality of life. We then aggregate these evaluations to obtain, for each drug, a multi-criteria evaluation vector representing the collective opinion of the consulted clinicians. Subsequently, the ELECTRE Tri-C and ELECTRE Tri multi-criteria methods are used for the evaluation of the polypharmacy and its assignment to one of the three categories: inappropriate, more or less appropriate or appropriate.

■ TE-29

Tuesday, 16:45-18:15 - 303B

Technical and financial aspects of energy problems

Stream: Technical and financial aspects of energy problems

Invited session

Chair: *Irena Milstein*

Chair: *Afzal Siddiqui*

1 - Combining strategic and operational uncertainty in long-term power system planning

Christian Skar, Héctor Marañón-Ledesma, Asgeir Tomasgard

Managing computational tractability in planning models where strategic and operational decisions are co-optimized is challenging due to the long time horizon needed for strategic planning, and the fine temporal granularity needed to capture short-term dynamics in the operational planning. When adding uncertainty to the mix this becomes even more problematic. In this talk we present a stochastic programming framework for long-term planning of the European power system where both long-term and short-term uncertainties are included. Our model is kept computational tractable by formulating the problem as a multi-horizon stochastic program. This is a hierarchal setup with a top-level multi-stage stochastic program (over a scenario tree) for the strategic decisions. For each strategic decision node in the scenario tree there is an embedded second-level stochastic program for the operational decisions. The underlying assumption in this framework is that future realizations of strategic uncertainty is independent of the past realizations of the operational uncertainty. In addition, future strategic and operational decisions are independent of past operational decisions. We will discuss the magnitude of the reduction in computational burden achieved by using this framework, and present a decarbonization study of European power system where our model has been applied.

2 - The effect of uncertainty on capacity and prices in competitive electricity markets

Irena Milstein, Asher Tishler, Nurit Gal, C.k. Woo

Lower average electricity price has been one of the main justifications for electricity market deregulation. However, electricity markets face uncertainties that are likely to create very high price volatility that, in turn, may cause regulators and politicians to avoid deregulation and maintain a (possibly less efficient) regulated electricity market with large capacity and stable electricity prices, or intervene in the process of price setting in deregulated electricity markets. This paper develops a two-stage model with endogenous capacity and operations to assess the effects of three types of uncertainties in competitive electricity markets: (a) demand uncertainty; (b) uncertainty in capacity availability (i.e., some of the installed capacity, such as weather-dependent PV technology, is available only intermittently); and (c) fuel cost uncertainty. We compare the effects of these uncertainties on optimal capacity, generation and prices by applying the model to stylized data of the Texas and California electricity markets. Our model provides the regulator with theoretical and empirical means to decide how to intervene in the market when it is affected by demand uncertainty, whether it has to promote renewable technologies, or should it intervene in the spot market for natural gas.

3 - Investment in an asymmetric duopoly under risk aversion

Kazuya Ito, Ryuta Takashima

In recent years, various financial problems have occurred throughout the world. It is important to have a lot of information for decision making to deal with such financial problems. An economic evaluation is applied as information for decision making on investment projects. However, in real investment projects, there are many uncertainties about income, costs and economic circumstances. The real option theory is a method that considers the situation with such uncertainties and that gives flexibility than conventional economic evaluation as the net present value method. In this work, we examine an influence of risk averse on investment decisions in a pre-emptive duopolistic market that compete leader's position by means of the real options theory. We analyze the investment timing of leader for entering the duopolistic market for the cost and the degree of risk aversion by fixing the follower's threshold. As results of the analysis, under the asymmetric risk aversion, we find that incentives for leaders and followers entering the duopolistic market could increase or decrease. Furthermore, the leader has demerit incentive for investing to entering the market from the influence of the risk aversion and the demand of the market. In the case of analysis with respect to the threshold of the leader with the fixed threshold of the follower, it turns out that the threshold of the leader changes despite of the threshold of the follower is fixed due to the effect of risk aversion.

4 - Investment in renewable energy under uncertainty in Norway and Sweden
Maria Lavrutich, Verena Hagspiel

In this paper we use a real options approach to examine the optimal decision to invest in a renewable energy project from the perspective of investors in Norway and Sweden under political uncertainty. In order to attract sufficient investments in the renewable energy projects, these countries have implemented a green certificate subsidy system, where the certificates are traded on a common market. The original agreement had an end date of the policy scheme in 2035. Energy producers that are eligible for green certificates will receive these from the date of approval for a maximum of 15 years. A Norwegian investor, however, has a deadline to invest by 2021 to receive green certificates, whereas a Swedish investor will receive green certificates regardless of the time of investment, but only until 2035. Norway initially had the investment deadline to receive green certificates set to 2020, but later extended it for one year. At the moment, it is uncertain if the policy will be further revised as they approach the Norwegian investment deadline. Sweden has sent signals that they are considering to extend the investment period from 2035 to 2045. The investors in both countries are, therefore, exposed to the uncertainty in green certificate prices, as well as the risk that the support scheme will be revised. In our paper, we evaluate the investment behavior using a case study about wind power, and analyze how investments are affected by policy uncertainty.

■ TE-30

Tuesday, 16:45-18:15 - 304A

Optimization of biomass-based supply chains

Stream: Biomass-based supply chains
Invited session
Chair: Taraneh Sowlati

1 - Operational level transshipment problem in forest-based biomass supply chains
Krishna Teja Malladi, Taraneh Sowlati

In this talk, we present a transshipment model for optimizing logistics and transportation of forest-based biomass supply chains. The model considers multiple products, heterogeneous fleet of trucks with a planning horizon of one week. Decisions related to pre-processing, storage of biomass at intermediate storage yards and flow values in truckloads as well as the number of trucks needed to handle the weekly operations are made in the model. The model is applied to a real case study of a third party logistics provider in British Columbia, Canada. We present the unique aspects of the model, which were not considered in the literature before, and the results of the case study.

2 - Integrated biomass to bioenergy and biofuel supply chain optimization
Shaghaygh Akhtari, Taraneh Sowlati

This study presents the development and implementation of an integrated optimization model for supply chain planning of biomass to bioenergy and biofuel products. This multi-period optimization model maximizes the profit generated from sales of products and addresses the tactical and operational decisions related to biomass procurement, transportation, and inventory levels while incorporating the operational parameters including forest biomass availability and quality factors. The potential use of the model is illustrated using realistic data from a case study located in the Interior British Columbia, Canada.

3 - Incorporating social benefits in multi-objective optimization of forest-based bioenergy and biofuel supply chains
Taraneh Sowlati, Claudia Cambero

An indicator for the potential social benefit of a new forest-based bioenergy and biofuel supply chain will be presented. The indicator considers different impacts of jobs based on their type and location. It is incorporated into a multi-objective mixed integer linear programming model that maximizes the social benefit, net present value and greenhouse gas emission saving potential of producing biofuels and bioenergy. The model is applied to a case study in Canada where different utilization paths for available forest and wood residues are investigated. The multi-objective optimization model is solved using a Pareto-generating method.

■ TE-31

Tuesday, 16:45-18:15 - 304B

OR in industry, software, software for OR

Stream: OR in industry, software for OR (contributed)
Contributed session
Chair: Jordi Mateo

1 - Railway timetabling and train dispatching under stochastic conditions
Jawad Elomari, Markus Bohlin, Martin Joborn

The iron ore line transports cargo from north of Sweden to the port of Narvik in Norway by rail, and then by sea to Europe and the Middle East. The railway is owned and managed by two infrastructure managers (IM), while six railway operators (RO) share access to it. From the IMs' perspective, creating an annual timetable that the ROs approve is not trivial, as capacity is limited, transported cargo differs, and the ROs prioritize objectives differently. The line is currently congested and the accuracy of its operations is not satisfactory. Moreover, the ROs would like to increase their production but need to figure out if transporting the additional output is even feasible with the current infrastructure. This question is equally important to the IMs since they need to know if the line can be better utilized, or if an expansion is needed and by how much. For the ROs, it is also important to achieve resource efficient circulations for engines and wagons that fits well with the timetable. In this work we consider the problem of annual timetabling facing rail operators who need to share access to rail infrastructure, and also need to find efficient vehicle circulations. The problem is considered from the operators' perspective as a rolling stock rostering problem under stochastic demand and transportation times. The problem is modelled mathematically and we present solution techniques for it.

2 - Global inventory planning with coupled Markov decision processes
Eric Prescott-Gagnon, Thierry Moisan, Yossiri Adulyasak

Inventory planning is the process of determining inventory quantities at the best trade-off between demand satisfaction and overall costs. In this paper we present a general approach to plan the level of inventory of multiple slow-moving items in a single location. Inventories of slow-moving items are particularly difficult to manage due to their sporadic demand. In addition, the uncertainty distribution of such demand does not necessarily match a well known distribution profile. Therefore, traditional inventory methods that assume a certain form of demand distribution to determine inventory policies do not perform well. Moreover, to mitigate the risk in practice, it is also common to impose targets for demand satisfaction (service level) or budgets on a group of items rather than an individual item. We present an approach to determine a set of inventory policies for a large number of items in the same group. To satisfy the global targets, we develop a column generation algorithm where a master problem is used to select a set of policies for all the items in the group with the objective to minimize overall costs while satisfying these targets. A set of subproblems, one for each item, is used to generate new inventory policies that are then added to the master problem. Each subproblem is a Markov Decision Process (MDP) based on a discrete distributional demand profile to model the inventory. The approach is then evaluated using a cross-validation simulation.

3 - Maintenance cost optimization of offshore gas installations

Rogelio Emmanuel Jauregui Miramontes, Pasi Luukka, Mikael Collan, Yuri Lawryshyn

Optimization of maintenance strategies continues to be an important research topic in academia and can have a significant impact on operating costs in industrial settings. The objective of this research is to utilize simulation in an effort to establish optimal maintenance strategies associated with an offshore oil installation. Our model consists of three systems in series with each system consisting of two or three major components operating in parallel. At least one or two components of each system must be operable for the installation to operate. A key feature of our simulation model is that we use real failure data, integrated with survey results, to estimate the probability of component failure. The component failure time consists of two aspects, namely, the failure hazard function associated with failure, and the historical maintenance quality performed on the component. The improvement factor (IF) has been introduced in the past as a measure to quantify the maintenance quality in an effort to better estimate the hazard function, post maintenance. However, little work has been presented to estimate the IF in industrial applications. We propose an enhanced methodology for calculating the IF based on expert judgment, fuzzy logic, and survey data. By utilizing our enhanced IF, we believe our model to be more realistic leading to improved maintenance strategies.

4 - Deterministic linear optimization as a service

Jordi Mateo, Kevin Borrell, LluisM Pla, Francesc Solsona, Adela Pages Bernaus

This work proposes a prototype of new software as a service (SAAS) to bring the huge potential and benefits of linear optimization to daily activity of small companies and ordinary people. The major contribution of this work is the design and implementation of a service that combines the potential of some of the most popular open-source solvers, such as lpsolve, glpk, cbc, symphony among others, with the capabilities of cloud computing. The only requirement to execute a model and analyze its results is an electronic device connected to the net. The results obtained show the usability and the competitive advantages of using the proposed service for decisions makers in any real life activity.

Wednesday, 8:30-10:00

■ WA-01

Wednesday, 8:30-10:00 - 307B

Financial modeling 1

Stream: Decision making modeling and risk assessment in the financial sector
Invited session
Chair: *Efsun Kürüm*
Chair: *Sebastien Lannez*

1 - FICO optimization: A use case about optimizing credit line increase
Sebastien Lannez, Livio Bertacco, Zsolt Csizmadia, Neill Crossley, Susanne Heipcke

Helping Credit Management Domain Experts Optimize Credit Line Increases with FICO Optimization, a credit management strategy analyst can define and optimize complex decision problems using an intuitive graphical workflow. In this talk, we will show how an analyst user, without prior experience of optimization, can create a credit line increase optimization application. This business problem aims at determining the best credit line increase to be offered to the customers in a lender's portfolio. In order to comply with regulatory constraints and company policy the solution must satisfy certain budget and loss limits, as well as ensure the increases will generate profit. Various artefacts, like PMML probability models or equation components defining the overall profit of each action on each customer, are combined and linked together to form the Decision Impact Model, a graphical model representing the full decision making process that leads to the offering. This Decision Impact Model is automatically transformed by FICO Optimization software into optimization problems, simulation routines or scoring algorithms, without any intervention from the end user. The output from different scenarios can then be compared using the built-in dashboards making it simple to benchmark business-as-usual or challenger solutions from a simulated decision process, against optimized solutions generated by Xpress-Optimizer.

2 - Residential real estate investment: Optimal holding period with taxation
Jean-Luc Prigent, Charles-Olivier Amedee-Manesme, Fabrice Barthélémy, Philippe Bertrand

This paper deals with residential real estate portfolio optimization under taxation. In this framework, we examine an important decision making problem, namely the determination of the optimal time to sell a real estate. Our aim is to better emphasize the impact of the taxation on the optimal holding period, extending previous results of Baroni et al. (2007). In this framework, the key parameters are the time horizon and the various taxes such as taxes on the rent and on the capital gains. The optimization problem corresponds to the maximization of the expectation of both the free cash flows and the terminal value of the portfolio. We introduce various taxes and in particular several specific degression functions on the capital gains. Then, we study the behaviour of the optimal time to sell for various financial parameter values and taxation levels. We show that the introduction of taxation highly modifies the structure of the optimal time to sell the real estate asset. For example, this latter one can jump very significantly whereas the expectation of the global wealth is a continuous function with respect to time. We provide numerical illustrations to emphasize such features and to examine the impact of various market and taxation parameters. We also compare the impact of different degression functions on the capital gains for US and several European countries. Our results have important implications for the operational management of real estate portfolios.

3 - Mean-variance indifference pricing
Yang Shen

We propose a new theory of derivatives pricing: mean-variance indifference pricing, which synthesizes the idea of utility indifference pricing and Markowitz's mean-variance analysis. We develop the theory under continuous-time Markovian regime-switching models, with a focus on unhedgable risk due to market incompleteness and regime switches. As the mean-variance problem is time-inconsistent, Bellman's dynamic programming principle is not applicable. We resort to the notion of equilibrium in game theory and solve the problem via an extended regime-switching HJB equation. We find that the buyer's and seller's indifference prices are both given by nonlinear pricing operators, which are not only mathematically neat, but also have profound financial implications. In fact, the buyer's (resp. seller's) indifference price equals a linear price minus (resp. plus) correction terms accounting for the volatility of the derivative in the linear pricing framework and quantifying instantaneous fluctuations from the financial market and structural changes of macro-economic conditions. As application, we compute mean-variance indifference prices of European call and put options. Our ultimate objective is to apply the buyer's and the seller's indifference pricing formulas to calibrate model parameters from the bid-ask spread observed in the real market. Particularly, the estimated risk aversion parameters of the representative buyer and seller can serve as good indicators for market sentiment.

4 - Equilibrium asset pricing with incomplete information on regimes
David Christen, Bernhard Nietert

When analyzing asset pricing with incomplete information on regimes, the role of different preference functions is already clarified (Ai (2010)). What is not equally well understood is, first, the effect of heterogeneous models of regimes and cash flows on the equity risk premium and, second, the nature of incomplete information as a second source of risk. We show, first, that incomplete information as second source of risk contains systematic risk although it does not consist of 100% systematic risk. Moreover, there is no risk premium on noisy signal meaning that signals do not change the decomposition of total risk into systematic and unsystematic components. Second, when comparing complete and incomplete information risk premia the functional dependence of cash flows on regimes matter most: whenever there is a lagged influence of regimes on cash flows, incomplete information risk premia tend to be lower than complete information risk premia. However with a non-lagged influence the difference between incomplete and complete information risk premia can assume arbitrary signs.

■ WA-02

Wednesday, 8:30-10:00 - 308B

Metaheuristics for routing and other problems

Stream: Metaheuristics - Matheuristics
Invited session
Chair: *Kenneth Sörensen*

1 - Routing - efficient and simple
Florian Arnold, Kenneth Sörensen

Routing problems are among the widest-studied area in combinatorial optimization. Due to the problem complexity, a major research stream on heuristics has evolved, to find high-quality solutions in a feasible time. The success of heuristics has triggered a race for ever better and faster solution methods. This race has changed the research focus heavily towards the metrics accuracy and speed. In exaggerated words, a heuristic has to produce excellent solutions on benchmark instances in order to be published. As a consequence, many state-of-the-art heuristics have become extremely complex, both in the design and the amount of parameter that they involve. This complexity makes it difficult to study the impact of components and generate a deeper understanding of why the heuristic works well. Also, complex heuristics can barely be reimplemented (to validate results or reuse it in another context). In the following work, we aim to demonstrate that a simply-designed heuristic based entirely on a well-implemented local search is sufficient to compete with the best heuristics in literature on numerous routing problems. We combine three of the most powerful local search techniques, and implement them in an efficient way. Furthermore, we demonstrate how to use and generate problem-specific knowledge, to guide the search to promising solutions more effectively.

2 - A GRASP with restarts heuristic for the Steiner traveling salesman problem
Celso Ribeiro, Ruben Interian

Given a set of nodes and the distances between them, the traveling salesman problem (TSP) consists in finding the shortest route that visits each node exactly once and returns to the first. The Steiner traveling salesman problem (STSP) is a variant of the TSP that assumes that only a given subset of nodes must be visited by a shortest route, eventually visiting some nodes and edges more than once. In this paper, we extend some classical TSP constructive heuristics and neighborhood structures to the STSP variant. In particular, we propose a reduced 2-opt neighborhood and we show that it leads to better results in smaller computation times. Computational results with an implementation of a GRASP heuristic using path-relinking and restarts are reported. In addition, a set of test instances and best known solutions is made available for benchmarking purposes.

3 - Visual attractiveness in vehicle routing problems
Daniele Vigo, Diego Gabriel Rossit

In Vehicle Routing Problems, besides the main objective of optimizing quantitative performance measures of the solution (e.g. length or cost), severa additional, often subjective measures are important. We focus here on such a goal, namely optimizing the visual attractiveness of routes since generating "nice" routes which are also sufficiently efficient is important to improve their acceptance by planners and facilitate the implementation of a routing plan. We present preliminary results on the development of heuristics to enhance visual attractiveness in Vehicle Routing Problem. Tests on benchmark instances show that the heuristic is able to find good solutions for different traditional visual beauty measures.

4 - The generalized Steiner cable-trench problem with application to error correction in vascular image analysis
Eric Landquist, Francis Vasko, Gregory Kresge, Adam Tal, Yifeng Jiang, Xenophon Papademetris

The Cable-Trench Problem (CTP) is the problem of connecting buildings on a campus to a building housing the central server so that each building is connected directly to the server via a dedicated underground cable. This problem is modeled by a weighted graph in which the vertices represent buildings and the edges represent the only allowable routes for digging trenches and laying cables between two buildings. Edge weights typically represent distance. A Steiner version of the CTP considers the possibility in which some subset of the buildings is connected to the central server. In this talk, we define the Generalized Steiner CTP (GSCTP), which considers the situation in which, even for the same distance, the cost of digging a trench is more costly for some edges versus others because of soil composition or physical obstacles, for example. The GSCTP has several natural applications, but we will focus on its nontrivial and novel application to the problem of digitally connecting micro-CT scan data of a vascular network and eliminating false-positive results. The CTP and its variants are NP-hard, so determining exact solutions to very large instances of the GSCTP are computationally infeasible. However, we show that straightforward modifications to Prim's algorithm find very good approximations to exact solutions to the GSCTP efficiently. This solution strategy allows us to fully automate the error-correction process in our application to vascular image analysis.

■ WA-03

Wednesday, 8:30-10:00 - 200AB

Keynote speaker: Avishai Mandelbaum

Stream: Keynote sessions
Keynote session
Chair: Elise del Rosario

1 - Theompirical research in OR/IE/OM: A theory- and data-based journey through service systems
Avishai Mandelbaum

I shall describe a personal research journey through service systems (e.g. telephone and chat centers, hospitals, banks,...). I view these systems through OR/OM/IE lenses, often more specifically as a queueing scientist (e.g. "enjoying" congestion and flows), and sometimes using operational characteristics as surrogates for financial, psychological and clinical performance. The theory of queueing is ideally suitable for capturing the operational tradeoff that is at the core of any service: quality vs. efficiency. Three cases in point are the Erlang-A, -R and -S models: the first has become a common call center model, by accommodating the choice that customers enjoy, namely wait for service or abandon; the second arose from emergency departments, in which returns to service are prevalent; and the third captures operational symmetry between servers and customers. All three models, or their (asymptotic) fluid or diffusion counterparts, parsimoniously yet valuably portray complex realities. Here value is tested against real service systems, which is in contrast to prevalent OR/OM/IE practice. (In that practice, models are often remote from data, and the value of fluid/diffusion models is judged by its accuracy relative to alternative models.) The ultimate goal of my research is an automatic creation, in real-time, of data-based models for service operations—analytical and simulation. The latter will serve as a validation ground for the former, and both will be universally accessible for applications by researchers, students and practitioners. Prerequisites include, first and foremost, measurements of individual events (e.g. patient-physician transactions), which then support inference of model primitives, structure and protocols. The above goal has been pursued at the Technion IE&M, with data-support by its SEE Laboratory (SEE = Service Enterprise Engineering).

■ WA-04

Wednesday, 8:30-10:00 - 202

Location, logistics, transportation and traffic 5

Stream: Location, logistics, transportation, traffic (contributed)
Contributed session
Chair: Danilo Tagliolato

1 - Industry 4.0 and the full integration of supply chains
Danilo Tagliolato, Cristiano Morini

The talk was designed in three parts. First, it presents the identification of the main characteristics of the technologies of the Industry 4.0. The research then explores the management of current supply chains in a globalized context and the challenges faced by multinationals. The final part is about how Industry 4.0 technologies can operate within supply chains in a globalized world. Data were collected through a systematic review of the literature, also considering the work of consulting firms, available in English and German languages. According to the survey, Industry 4.0 seeks to optimize industrial processes through standardization, with the help of new technologies such as Cyber-Physical Systems, Internet of Things and Smart Data, increasing product variability and flexibility. The global supply chain deals with a multinational association with its suppliers and customers around the world, making it complex and fragile to any market oscillation. The technologies of Industry 4.0 seek to simplify the management of these chains, in which the interaction between the physical and the virtual world is essential for the company to supervise the movement of its merchandise along this network of supplies, arising terms like "Control Towers". The visibility of a supply chain will be a key factor for global supply chains.

2 - Approximating the multiple-vehicle routing problems

Yichen Yang, Zhaohui Liu

Two variants of multiple Hamiltonian path problem are considered. The general multiple Hamiltonian path problem is to find m paths for m vehicles such that all the destination are visited exactly once and the total cost is minimum. One variant is the multiple-terminal vehicle routing problem (MDMTVRP), where the m vehicles must start and end at the prefixed m depots and m terminals. Another variant is the single depot multiple-vehicle routing problem (SDMVRP), where m vehicles start at the single prefixed depot and there is no restriction on the terminals. The edge costs are assumed to be non-negative, symmetric and satisfy the triangle inequality. For the MDMTVRP, we first improve Bae's constrained forest based algorithm for the MDMTVRP. We prove the approximation ratio of our algorithm is 2-1/(2m+1). And the approximation ratio is shown to be tight. We also present an asymptotic 5/3-approximation algorithm for the MDMTVRP which runs in polynomial time for fixed m. For the SDMVRP, we present a 2-2/(m+4) approximation algorithm. The approximation ratio is also shown to be tight. And we also present a 5/3-approximation algorithm with polynomial running time for fixed m.

3 - Centralized combinatorial auctions for the procurement of TL transportation services: What benefits for the carriers?

Intissar Ben Othmane, Monia Rekik

Combinatorial auctions have been proved to be efficient market mechanisms for the procurement of transportation services. Traditionally, shippers run combinatorial auctions separately, independently one of another. Carriers compete in each auction to try to win lanes (origin-destination pairs) that are profitable for them with no guarantee that all the submitted bids are won. These auctions can be run either simultaneously or sequentially forcing carriers to take risks when generating and submitting their combinatorial bids. Hence, it may be interesting to consider a centralized market in which several shippers run together a single combinatorial auction so that carriers are offered the possibility to submit bids on all shippers' contracts at the same time. This study compares between centralized and decentralized simultaneous combinatorial auctions from the carrier perspective. Results show that, in most cases, centralized auctions allow carriers to increase their expected profit, their market diversification while reducing greenhouse gas emission.

4 - Reduction of greenhouse gases emissions by using different routing problems

Juraj Pekár, Ivan Brezina, Zuzana Čičková

Nowadays a reduction of environmental externalities of greenhouse gases emissions is of great importance. Unsurprisingly the transport is one of the areas significantly contributing to the production of emissions. Therefore it is important to use integrated approaches to minimize CO2 emissions in this area. The optimization in the transport logistic field can be supported by using various mathematical models allowing for more efficient transportation. One of important areas is analyzing various routing problems. The routing problems affecting the greenhouse gases emission can be characterized in two ways: classical models and special models aimed on CO2 reduction. Even the use of models with a primary objective to minimize transport costs brings the side effect of reducing emissions. Main source of emissions reduction are shorter routes, better management of vehicle loads, and usage of more appropriate vehicle types. On the other hand, there are widely developed specialized models aimed directly at reduction of greenhouse gases emission. Authors researched selected models of routing problems considering their impact on CO2 emissions.

■ WA-05

Wednesday, 8:30-10:00 - 203

Stochastic modeling and simulation in engineering, management and science 4

Stream: Stochastic modeling and simulation in engineering, management and science
Invited session
Chair: *Ceylan Yozgatligil*
Chair: *Gerhard-Wilhelm Weber*
Chair: *Shangwei Xie*

1 - Sequencing with stochastic release dates

Claus Gwiggner

We study the problem of determining an a priori sequence of tasks subject to uncertain release dates. We follow a two-stage approach, where a sequence is established in the first stage and a re-sequencing operation is performed in the second stage. In its simplest form, the second stage can be solved analytically. We derive the expected recourse cost of a given sequence by the help of a non-homogeneous Markov Chain and find optimal solutions to the problem for instances with huge variability.

2 - Forecasting short-term electric energy demand in Australia, Brazil and G7 countries through Bagging exponential smoothing methods

Erick de Oliveira, Fernando Luiz Cyrino Oliveira

Ensuring an adequate supply of energy is a pressing national priority in almost every nation in the world. One kind of time series which is of major interest, from both academic and practical perspectives, is the short-term electric energy consumption. In this connection, this paper expands the fields of application of combined Bootstrap aggregating (Bagging) and exponential smoothing methods to the electric sector in order to obtain more accurate demand forecasts. Different approaches are tested using monthly data from 9 countries (Australia, Brazil and G7 countries) and a comparative out-of-sample analysis is conducted on the basis of several performance metrics. The results show that a combination of a seasonal-trend decomposition, a moving block bootstrap (MBB) aggregation approach and specific exponential smoothing methods can substantially improve the forecast accuracy of the demand for energy end-use services in different countries. In many cases the gains are noteworthy when compared with single forecasts on the real data. For the Australian electricity consumption, for instance, the symmetric Mean Absolute Percentage Error and the Root Mean Squared Error obtained using a MBB Multiplicative Holt-Winters approach were almost 49% and 60% lower than the ones obtained in a single Multiplicative Holt-Winters forecast on the real data. It is our belief that equally satisfactory results can be reached on other occasions such as different countries and time series.

3 - Methods to compare expensive stochastic optimization algorithms

Shangwei Xie

Analyzing test data of optimization algorithms under random restarts is challenging. The data need to be resampled to estimate the behavior of the incumbent solution during the optimization process. The estimation error needs to be understood in order to make reasonable inference on the actual behavior of the incumbent solution. Comparing the performance of different algorithms based on proper interpretation of the estimator is also very important. We model the incumbent solution of the optimization problem over time as a stochastic process and design an estimator of it based on bootstrapping from test data. Some asymptotic properties of the estimator and its bias are shown. The estimator is then validated by an out-of-sample test. Three methods for comparing the performance of different algorithms based on the estimator are proposed and demonstrated with data from a real-world problem.

■ WA-06

Wednesday, 8:30-10:00 - 204A

Optimization in humanitarian logistics

Stream: Humanitarian logistics
Invited session
Chair: *Walter Gutjahr*
Chair: *Begoña Vitoriano*

1 - Humanitarian facility location and supply prepositioning under road vulnerability
Melih Çelik

An important challenge in relief item and service delivery in the aftermath of a disaster is that roads may become unusable. In this study, we propose a multi-echelon humanitarian logistics network design by incorporation of demand uncertainty and road-facility vulnerabilities. The specific problem we consider consists of locating distribution centers and prepositioning supplies in the pre-disaster stage, and routing of deliveries in the aftermath. Given the uncertainty of various aspects of the disaster, we develop a two-stage stochastic programming model. The model is executed under efficiency and equity-based objective functions. To solve real-life sized instances, we propose a heuristic approach based on sample average approximation. We test our models on real-life disaster scenarios for Istanbul, Turkey to observe the effect of different performance measures, budget restrictions, and road-facility vulnerabilities.

2 - Humanitarian logistics: Warehousing and transportation models
Begoña Vitoriano, M. Teresa Ortuno, Adán Rodriguez

Logistics for disaster management includes four main groups of activities to be developed: assessment, procurement, warehousing and transport. They are developed along the disaster management cycle, including strategic, tactic and operational activities and decisions. Therefore, optimization of humanitarian logistics processes could be focused on different phases and type of activities. However, optimization models show their main power on warehousing and transport. Two main factors must be taken into account when developing models in this context: uncertainty and optimization criteria. Uncertainty will be higher when developing activities in the preparedness phase, since strategical and tactical decisions are developed in advance, prior to facing a concrete event; and decreasing in response where assessment is the first activity that takes place together with the rescue and evacuation. In this way, stochastic and robust programming appear as useful tools. Regarding optimization criteria, it must be taken into account that effectiveness is the main aim in humanitarian operations, even more than efficiency. But measuring effectiveness in this context is not clear, since a lot of factors affect the performance: time response, budget, equity... In this presentation, optimisation models incorporating uncertainty and several criteria will be shown, for both, warehousing (including facility location) and transport.

3 - Trajectories, lexicographic goals and incident controller's regret: Formulating objectives in the presence of an emergency
Natalie Simpson, James Minas

Decision making during emergencies is often the responsibility of the Incident Controller or Incident Commander, a single party who develops solutions before the nature of evolving problems are fully known. In this study, we examine a range of emergencies and identify the quintessential elements of this decision making challenge, which we refer to as the Incident Controller's Problem. We argue that successful emergency response seeks the most efficient means of minimizing the gap between current conditions and benchmarks of normality or safety, revising this assessment throughout the time-line of the incident. Modeling this practice as an iterative lexicographic goal program illustrates how this framework lessens a decision maker's reliance on the quality of forecasting, but also results in scenarios that, when examined in hindsight, may suggest the Incident Controller over-reacted. We triangulate these findings through numerical simulations and surveys of related literature.

4 - Exploratory study of the anticipation effects in post-disaster environments
Diana Ramirez-Rios, Jose Holguin-Veras, Luk Van Wassenhove, Victor Cantillo, Shaligram Pokharel, Johanna Amaya, Trilce Encarnacion

This research uses contingent valuation experiments to gain insight into the anticipation effects - defined as the anxiety and deprivation of a critical supply - present in post disaster environments. Quantification of such effects would enable disaster responders to gain insight into how best to allocate critical resources in post-disaster environments. For this purpose, a stated preference survey was conducted to assess the economic value of drinkable water in deprivation conditions, namely, the willingness-to-pay for a bottle of water. The designed scenarios used as experimental variables: the amount of time the respondent has been deprived of water; the expected time for a return to normalcy; and the amount of money available to the respondent at the time of the deprivation. The data were used to estimate econometric models that express the willingness-to-pay as a function of relevant variables. These models provide an understanding into the significance of anticipation effects, and their influencing factors. From the results obtained, we discuss important implications for disaster management and suggest a number of actions to mitigate these effects.

■ WA-07

Wednesday, 8:30-10:00 - 204B

Vehicle routing problems

Stream: Vehicle routing
Invited session
Chair: *Lina Simeonova*

1 - Modelling customer dependencies in the probabilistic traveling salesman problem
Pascal Wissink, Jamal Ouenniche

Recent attempts to capture uncertainty in routing problems have led to a variety of stochastic alternatives of the travelling salesman problem. Many of the stochastic variants of the traveling salesman problem rely on independent and identically distributed (i.i.d.) variables for travel times, node demands and customer presence. However, these variants tend to neglect the possibility that real-life problems may be characterised by dependency structures between the stochastic elements. This study employs the Bahadur-Lazarsfeld expansion distribution to model dependencies in the stochastic customer presence of the probabilistic travelling salesman problem. We demonstrate that, although computationally intensive, the calculation of the expected length of a tour under multivariate conditions does not require the full enumeration of every possible tour. For specific parameter choices, our model can be shown to reduce to the traditional expression for the expected length of a probabilistic travelling salesman's tour with i.i.d. Bernoulli customer presences.

2 - The best network improvement for multi-depot vehicle routing problems in an incomplete network
Corrinne Luteyn, Pieter Vansteenwegen

In this research, a number of Multi-Depot Vehicle Routing Problems are considered in an incomplete network. We will propose two solution approaches to determine the best single improvement or best set of improvements of this incomplete network, such that the total travel time of the vehicles in these routing problems is minimized. This problem originates from the situation in a number of (Dutch) cities where a large part of the logistics within the city area are performed by one transport company. In this case, this company will be able to suggest its most beneficial improvements to the network to the traffic manager. Favoring this transport company will reduce the traveled vehicle kilometers within the city area. In this research, three possible network improvements are considered: (re-)opening pedestrian zones for vehicles, widening existing roads and converting existing roads into one-way roads with a higher speed. The first approach is a Three-Phase Heuristic, which consists of a construction phase, an analysis phase and a testing stage. The second approach is an Adaptive Large Neighborhood Search (ALNS). This ALNS consists of a unique set of destroy and repair methods. The performance of our heuristic is evaluated on a set of benchmark instances based on a realistic road network with a varying number of customers and vehicles. Additionally, the solution quality is compared to that of solutions obtained using exact solution techniques.

3 - Real time control and routing of AGV for container hub ports
Ek Peng Chew, Loo Hay Lee, Zhipeng Qiu

We present a real time Automated Guided Vehicle (AGV) control and routing for a transshipment hub port. The model needs to solve a large system within a short time and address deadlock situation. We present a novel method which combines mathematical model and simulation model which attempts to minimize conflicts, congestion and prevent deadlock. Essentially, the approach uses a three-layer control architecture, which are the global path direction design, dynamic junction coordination, and adaptive local junction control. This approach will help to determine the schedule and routing of the large number of AGVs within a large network, and can be used to control the AGV movement in real time.

4 - The mixed fleet vehicle routing problem with demand-dependent service times and light loads: Formulation and population variable neighbourhood search with adaptive memory
Lina Simeonova, Niaz Wassan, Said Salhi, Gábor Nagy

In this paper we consider a real-life Vehicle Routing Problem, characterized by heterogeneous vehicle fleet, demand-dependent service times, maximum allowable overtime and a special light load requirement. A new learning-based Population Variable Neighborhood Search algorithm is designed to address this complex logistic problem. The computational experience suggests that savings up to 8% can be achieved when overtime and light load requirements are considered in advance. Moreover, accommodating for allowable overtime has shown to yield 12% better average utilization of the driver's working hours and 12.5% better average utilization of the vehicle load, without incurring extra running costs. The proposed metaheuristic method also shows some competitive results when applied to the special case of the real-life Vehicle Routing Problem, namely the Fleet Size and Mix Vehicle Routing Problem.

■ WA-08

Wednesday, 8:30-10:00 - 205A

Business analytics

Stream: Data science and analytics (contributed)
Contributed session
Chair: Dominique Welt

1 - A collaborative problem driven requirements engineering approach to design an HR analytics application
Lynda Atif, Camille Rosenthal Sabroux

The Requirements Engineering process is presented as a series of guidelines for activities that must be implemented to guarantee that the final product satisfies end-users requirements and takes into account the limitations identified. For this, we know that a well-posed statement of the problem is "a problem whose crucial character arises from collectively produced estimation and a formulation found to be acceptable by all the parties". Moreover, we know that DSSs were developed to help decision-makers solving their unstructured decision-making problems. So, we thus base our research on the assumption that developing DSS, particularly for helping poorly structured or unstructured decisions, cannot be done without considering end-user decision problems and how to represent and formalize them collectively. Our approach will reflect common end-user problems in the upstream design phase and in the downstream phase these problems will determine the design choices and potential technical solution. We will thus rely on a categorization of HR's problems for a development mirroring the Analytics solution .This brings out a new data-driven DSS typology: Descriptive Analytics, Explicative or Diagnostic Analytics, Predictive Analytics, Prescriptive Analytics.

2 - Optimal feature extraction and selection method for PdM (Predictive Maintenance) of roots-vacuum-pump in semiconductor manufacturing process
Kyuchang Chang, Youngji Yoo, Jun-Geol Baek

In this research, we propose an feature extraction and selection methods for PdM (Predictive Maintenance) of roots-vacuum-pump in semiconductor manufacturing process. The manufacturing process for semiconductor is very complex, and commonly consists of 100 steps. One of the important steps is CVD (Chemical Vapor Deposition) process. CVD is a widely used materials-processing technology applying solid thin-film coatings to surfaces. In this process the roots-vacuum-pumps not only supply some chemicals into chamber but also make chamber remain in a vacuum state. Problem is that by-product produced in the chamber creates load on pumps and sometimes pumps break down. As by-product consists of minute particles, it lays thick inside the pumps generating heat which causes fatal failure in pumps. Previous studies about vibration signal have limitation that they focus on simple equipment such as bearing which is relatively simple to analyze. Considering the complexity of vibration signal of pumps, this study suggest optimal feature extraction and selection method. This research will contribute to monitoring the state of the pumps and predicting the failure time.

3 - Optimization of shows schedules on linear television
Sebastian Souyris, Jaime Miranda

The hyper-competitive live and video entertainment industry offers to consumers an array of high-quality products to choose from like never before. At the same time, content providers must make decisions carefully in order to grow or maintain a profitable position. At a tactical level, decision makers must decide what shows to create and acquire in order to maximize the medium-term ratings. At an operational level, schedulers must program the shows in order to maximize the short-term target demographic viewership. In this talk, we present rating forecasting and show scheduling models that in conjunction lift network audience.

4 - Critical factors of success for implementing business intelligence initiatives in governmental organizations
Dominique Welt, Adnene Hajji

Business Intelligence (BI) systems for data mining and predictive analytics are becoming ubiquitous in organizations of all sizes and types. Due to the risky nature of implementing such systems, researchers such as Yeoh and Koronios (2010) have studied critical success factors (CSF) for the implementation of BI systems. The literature regarding such factors specific to the governmental sector is however scarce. By looking at the case of Quebec's Secrétariat du Conseil du trésor's "Système Intégré d'Information de Gestion en RH - Études Quantitatives", this paper aims at identifying the CFS regarding the implementation of a BI initiative in such contexts and gaining a better understanding on how they impact the outcome. The findings suggest that while the CFS identified in previous studies apply to the governmental context, the complexity of such organizations requires the addition of a "Environmental factors" dimension. These findings will allow BI specialists implementing such initiatives in governmental organizations to be aware of CSF specific to their context in order to improve their chance of success.

■ WA-09

Wednesday, 8:30-10:00 - 205B

Routing problems with time windows assignment

Stream: Discrete optimization in logistics and transportation
Invited session
Chair: *Jean-François Côté*
Chair: *Manuel Iori*

1 - Strengthened precedence inequalities for the TWAVRP

Kevin Dalmeijer, Guy Desaulniers

We consider the Time Window Assignment Vehicle Routing Problem (TWAVRP), the problem of assigning time windows for delivery before demand volume becomes known. In the literature, instances of this problem have been solved with a branch-price-and-cut algorithm and with a branch-and-cut algorithm. Recently, the latter has been shown to be superior, outperforming the former in terms of both speed and the number of instances that could be solved to optimality. Part of this superior performance, however, has been the inclusion of a new class of valid inequalities, the precedence inequalities, in the branch-and-cut algorithm. We recognize that the precedence inequalities can also be applied in a branch-price-and-cut setting. Furthermore, the precedence inequalities can be strengthened to provide better cuts, at the cost of a more difficult pricing problem. We create a branch-price-and-cut algorithm based on these improved cuts, and we present numerical results.

2 - The time window assignment vehicle routing problem with time-dependent travel times

Remy Spliet, Said Dabia, Tom Van Woensel

We introduce the time window assignment vehicle routing problem with time-dependent travel times. It is the problem of assigning time windows to customers before their demand is known and creating vehicle routes adhering to these time windows after demand becomes known. The goal is to assign the time windows in such a way that the expected transportation costs are minimized. We develop a branch-price-and-cut algorithm to solve this problem to optimality. The pricing problem that has to be solved is a new variant of the shortest path problem which includes a capacity constraint, time-dependent travel times, time window constraints on both the nodes and on the arcs, and linear node costs. We develop an exact labeling algorithm and a tabu search heuristic that incorporates a polynomial time algorithm designed to optimize the time of service on a given delivery route. Furthermore, we present new valid inequalities which are specifically designed for the time window assignment vehicle routing problem with time-dependent travel times. Finally, we present numerical experiments to illustrate the performance of the algorithm.

3 - A practical time slot management and routing problem in attended home delivery

Bruno Bruck, Jean-François Cordeau, Manuel Iori

We describe the solution methodology that we developed to address an attended home delivery problem faced by an Italian provider of gas, electricity and water services. This company operates in several regions and must dispatch technicians to customer locations where they carry out installation or maintenance activities within time intervals chosen by the customers. The optimization problem that we face involves three interconnected levels: (i) the design of the time slot tables, (ii) the simulation of customers' choices of time slots, and (iii) the design of a cost- effective routing plan of the technicians to serve customers requests. To solve the problem, we propose a large neighborhood search (LNS) heuristic that creates time slot tables by relying on various simulation strategies to represent the behavior of customers and on an integer linear program to optimize the routing of technicians. In addition, we also use a second integer program as a repair mechanism inside the LNS heuristic. Extensive computational experiments carried out on data provided by the company confirm the efficiency of the proposed methodology both in terms of cost and quality of service.

4 - The stochastic multi-period time windows assignment problem

Jean-François Côté, Alice Raffaele, Renata Mansini

This work addresses the challenge of establishing delivery schedules to consumers who buy goods online or buy furniture and appliances. The difficulties faced by home delivery companies are due to the high level of uncertainty of the future demand. Several works done in the past that tackled this problem assumed to some point that future demand is known or only considered daily schedules. As information systems have more and more historical data, it is possible to build scenarios of the future demand, and we propose a stochastic programming approach to offer more robust delivery schedules that span over several days. In this talk, we present a heuristic to solve the stochastic multi-period time windows assignment problem. We consider a home delivery company that wishes to plan the delivery schedules for a time horizon across a delivery area. The solution approach is based on the concept of a priori optimization. That is, time windows are assigned to the delivery zones in the first stage without taking into account the future demand. Then, in the second stage, future customers are known and routes satisfying the first stage time windows are planned. The objective is to minimize the expected cost of the second stage. The resolution approach consists of heuristics that tries to move the time windows to different periods in order to improve the current solution. Computational experiments demonstrate the value of this approach.

■ WA-10

Wednesday, 8:30-10:00 - 205C

Hub location

Stream: Location
Invited session
Chair: *Francisco Saldanha-da-Gama*

1 - Reliable single allocation hub location problem under hub breakdowns

Nicolas Kämmerling, Borzou Rostami, Christoph Buchheim, Uwe Clausen

The design of hub-and-spoke transport networks is a strategic planning problem, as the choice of hub locations has to remain unchanged for long time periods. However, strikes, disasters or traffic breakdown can lead to the unavailability of a hub for a short period of time. Therefore it is important to consider such events already in the planning phase, so that a proper reaction is possible; once a hub breaks down, an emergency plan has to be applied to handle the flows that were scheduled to be served by this hub. In this paper, we develop a two-stage formulation for the single allocation hub location problem which includes the reallocation of sources to a backup hub in case the hub breaks down. In contrast to related problem formulations from the literature, we keep the non-linear structure of the problem in our model. A branch-and-cut framework based on Benders decomposition is designed to solve large scale instances to proven optimality. Thanks to our decomposition strategy, we keep the structure of the resulting formulation similar to the classical single allocation hub location problem, which in turn allows to use classical linearization techniques from the literature. Our computational experiments show that this approach leads to a significant improvement in the performance when embedded into a standard mixed-integer programming solver. We report optimal solutions for instances much bigger than those solved so far in the literature.

2 - The green hub location-routing problem: A model and solution technique

Pierre Dejax, Xiao Yang, Nathalie Bostel, Marc Paquet

The hub location routing problem (HLRP) is an efficient system for long distance less than truckload (LTL) freight transportation from many origins to many destinations. In addition to the classical cost considerations, we investigate the environmental impact of the HLRP by considering the CO2 emissions related to the transport and handling operations. After investigating the relevant published literature, we propose a bi-objective optimization model for the HLRP in order to study the compromising relationships between the cost and emissions in such a system. We address the specific case of the Capacitated Single Allocation Hub Location Routing Problem (CSAHLRP) for separate collection and delivery processes. In attempt to giving an insight study on the problem, the bi-objective model is decomposed into two single objective models and a memetic algorithm (MA) is proposed to solve the two problems separately. Extensive experimentations based on the Australian Post (AP) data sets show that the MA can efficiently solve large instances, while solving the models with the CPLEX solver can only handle small and medium size instances. Furthermore, the results reveal the conflicts between the minimization of cost and CO2 emissions. Solutions are also compared to those obtained with a biobjective extension of the memetic algorithm in order to determine approximations of the Pareto fronts or by solving the biobjective models using the Epsilon constraint method.

3 - Exact solution of hub network design problems with profits

Elena Fernandez, Armaghan Alibeyg, Ivan Contreras

We consider two primary hub network design problems with profits that address the simultaneous optimization of the collected profit, setup cost of the hub network and transportation cost. Potential applications arise in the design of air and ground transportation networks, where companies need to jointly determine the location of hub facilities as well as the design of the hub network. A branch-and-bound algorithm is proposed for each problem that uses a sophisticated Lagrangean relaxation to obtain tight upper and lower bounds. The Lagrangean functions exploit the structure of the problems and can be decomposed into smaller subproblems that can be solved efficiently. In addition, simple reduction tests and partial enumerations are used to reduce considerably the size of the formulations and thus decrease the computational effort required to completely explore the enumeration tree. The proposed branch-and-bound algorithms have been tested computationally on a set of benchmark instances from the literature. The obtained results assess the efficiency of the proposal, which is clearly superior to the performance of a general purpose solver.

4 - A heuristic algorithm for r-allocation p-hub median problems

Francisco Saldanha-da-Gama, Angel Corberan, Rafael Marti, Juanjo Peiró

We study a class of hub location problems known in the literature as r-allocation p-hub median problems. We extend an existing modeling framework to include fixed allocation costs, non-stop services between terminals and uncertainty in traffic and costs. If such uncertainty can be captured by a finite set of scenarios, each of which having some known occurrence probability, it is possible to develop a compact formulation for the deterministic equivalent problem. However, even for small instances of the problem, the model becomes too large which prevents tackling it by means of a general-purpose solver. This fact motivates the development of an approximate procedure whose starting point is the determination of a feasible solution to every (deterministic) single-scenario problem. These solutions are then embedded into a process inspired by Path Relinking: gradually an initial solution to the overall problem is transformed by the incorporation of attributes from some guiding solutions. In our case, the guiding solutions are those found for the single-scenario problems. We report and discuss the results of the computational experiments performed using instances randomly generated for the new problem using the well-known CAB data set. In this analysis, we also include the relevance of embedded uncertainty in the class of problems investigated in this work.

■ WA-11

Wednesday, 8:30-10:00 - 206A

Inventory management

Stream: Supply chain management
Invited session
Chair: Stefan Minner

1 - On the optimality of reorder points: A solution procedure for joint optimization in 2-level distribution networks using (R,Q) order policies

Christopher Grob, Andreas Bley

We present an algorithm to minimize the investment in stock in a 2-level inventory distribution network with stochastic demands using a (R,Q)-policy. Our research is motivated by the inventory planning for a worldwide spare parts supply chain of an automotive company. The algorithm is fast enough to be used in real applications. It is, to our knowledge, the first one to determine optimal reorder points for inventory distribution systems using complex wait time approximations. Our algorithm permits various wait time models, including well-known models by Kiesmüller et al. and Berling and Farvid as well as a new one based on a negative Binomial distribution. The service constraints included in these models are non-linear and can be evaluated only using a time-consuming binary search. To cope with these challenges, we over- and underestimate the original non-linear constraints by piecewise linear functions, whose break-points are adaptively refined during the execution of the algorithm. To further speed up computations, we use a truncated binary search to compute initial over- and underestimates at the current break points and iteratively refine these values during the algorithm, continuing the binary search when necessary. Combining these two techniques, our algorithm converges to a globally optimal solution. Finally, we report on the result of our numerical study based on real world data, indicating a substantial decrease in stock compared to prescribed central fill rates.

2 - Multi-objective mathematical model of routing and inventories for the supply chain of perishables: The case of the fruit sector

Diego Fernando Batero Manso, Javier Arturo Orjuela Castro

The post-harvest loss in Colombia is mainly due to the inadequate planning and execution of the logistical processes in the supply chain (SC) of fruit (FSC), the high costs of inventories, transportation and distribution stand out to such a degree that improving them would improve the overall competitiveness of the fruit sector. The proposed models for FSC were identified through a systematic review of the literature. Then, with this design and the application and analysis of the results of a survey answered by the different links in the FSC, an Inventory Routing Problem (IRP) mathematical model was elaborated. Based on this model, strategies for improving the logistics of FSC were developed. A multi-objective, multi-product and multi-link mathematical model yielded distribution and inventory plans for five selected fruits. Experimenting with the mathematical model and the analysis of results, scenarios were evaluated and new strategies proposed for FSC in Cundinamarca. The proposed mathematical model allowed the identification of general strategies that applies to the CSF independently of the type of fruit. Production and inventory plans were defined and heterogeneous vehicles were assigned to the distribution plan found, this in a context of a mountainous region with large differences in altitude and climate. The implementation can be evaluated in terms of decrease in fruit loss and the level to which the resources allocated to the logistic process are being taken advantage

3 - Influence of production, transportation, and inventory flows on costs and service levels in a lost sales push-pull production-inventory system

Michael Vidalis, Georgios Varlas

Deciding supply chain production rates and inventory policies and determining their parameter values poses a challenging problem. Improved customer service levels can be obtained by linking production, stock and transportation processes. We consider a serial 3-echelon supply chain comprising of a provider, a distribution center (buffer) and a retailer that cooperate in the fulfillment of stochastic customer orders (compound Poisson). The material flow between upstream stages is push type, while between downstream stages it is driven by continuous review, (r, Q) quantity inventory control policy. Exponential distributed production and transportation times between stages are assumed. Unsatisfied external demand is lost. The system is modeled using matrix analytic methods as a Markov birth-and-death process. An algorithm is developed to compute the probability distribution for different system parameters. Key performance metrics, such as time averages of inventory and customer service levels can be computed at each echelon. The algorithm is programmed in Matlab' and the resulting model is validated against simulation results yielding good agreement. The algorithm can be used to evaluate different scenarios for supply chain design, or to explore the dynamics of a push-pull system.

4 - Multi-echelon inventory control for perishable products: Push or pull?
Stefan Minner

Managing perishable products in retail chains with a central depot and multiple stores faces additional challenges compared to the already complex multi-echelon problem for durable products. We analyze a periodic review system with stochastic demand and finite (short) shelf-life, as typically found in food supply chains. In a pull system, the retail stores determine their order quantities according to a base-stock policy and the depot places a consolidated order with the supplier. Upon arrival, orders are allocated to the stores. In the push system, a constant order quantity is placed with the supplier every period and allocated to the stores upon arrival. For both environments, we characterize optimal allocation policies. In a numerical study, we show the benefits of the simpler, but effective constant order quantity policy compared to base-stock policies.

■ WA-12

Wednesday, 8:30-10:00 - 206B

Multiple criteria decision making and optimization 1

Stream: Multiple criteria decision making and optimization (contributed)
Contributed session
Chair: *Farzaneh Ahmadzadeh*

1 - Inference rules for supplier selection using spherical metric function as a decider
Dickson E. A Omorogbe, Sunday Omosigho

This talk proposes the inference rules approach in resolving contradictory recommendation when more than one distance functions are adopted in intuitionistic fuzzy TOPSIS for supplier selection. The method helps to resolve the existing problem of contradiction in the ranking of suppliers when more than one metric functions are used in TOPSIS. Thus providing a platform for effective supplier selection instead of the prevailing practice in literature of using one distance function in TOPSIS which may be misleading in practice. A new procedure for supplier selection is recommended.

2 - Sustainable indicators for rural area and analysis of causal relationships using FDM and fuzzy DEMATEL
Wei-Ming Wang

Due to rising environment consciousness and perception of returning to rural nature, sustainable development of rural area has been increasingly valued these days. For practicing the sustainable development for rural area, it is essential to determine appropriate evaluation indicators. The purpose of this study is to find the impact factors that influence rural area sustainable development, to select the critical evaluation indicators, and to determine the causal interrelationships among these indicators. Since establishing sustainable indicators is a multiple criteria decision-making (MCDM) problem in nature, this study adopts a model which integrates fuzzy Delphi method (FDM) and the fuzzy Decision Making Trial and Evaluation Laboratory method (fuzzy DEMATEL). The FDM is applied to extract the critical factors from the possible impact factors. The fuzzy DEMATEL method is adopted next by inviting rural development experts to evaluate the importance of the indicators and to construct the causal interrelationships among the indicators. This study not only show the core dimensions and the sustainable indicators under each dimension for the sustainable development of rural area, but also the impact-relation maps among the indicators. The results of this study can provide useful guidance to rural area development, and can be reference for related policy making.

3 - A multiple criteria decision aid model for preanesthetic evaluation
Vincent Mousseau, Mohamed Amine Lazouni, Said Mahmoudi, Marc Pirlot, Olivier Sobrie

Challenges in the field of anesthesia and intensive care consist of reducing both anesthetic risks and mortality rate. The ASA score plays an important role in patients' preanesthetic evaluation. We propose a methodology to derive simple rules which classify patients in a category of the ASA scale on the basis of their medical characteristics. It is based on MR-Sort, a multiple criteria decision analysis model. The proposed method intends to support two steps. The first is the assignment of an ASA score to the patient; the second concerns the decision to accept — or not — the patient for surgery. So as to learn the model parameters and assess its effectiveness, we use a database containing the data of 898 patients who underwent preanesthesia evaluation. The accuracy of the learned models for predicting the ASA score and the decision of accepting the patient for surgery is assessed and proves to be better than that of other machine learning methods. Furthermore, simple decision rules can be explicitly derived from the learned model. These are easily interpretable by doctors, and their consistency with medical knowledge can be checked. The proposed model for assessing the ASA score produces accurate predictions on the basis of the (limited) set of patient attributes in the database available for the tests. Moreover, the learned MR-Sort model allows for easy interpretation by providing human readable classification rules.

4 - Multi-dimensional risk management by evidential reasoning approach
Farzaneh Ahmadzadeh, Carlos Jansson

Many factors have created an awareness of risk and its impact on industrial organizations including rapid technology evolutions, the global economy, and the changing role of engineering and business processes. Significant research has been done in the field of risk management but none of this previous research has provided a concrete solution for the application of risk management to solve common industrial problems. One main reason is considering just one dimension view of risk. The magnitude and severity of the consequences make it essential to develop a more appropriate and efficient form of risk management, which provide the positive output. Hence there is a need for a multi-dimensional assessment which enable more consistent decision making to be made and takes into account the decision makers preferences and the context of uncertainty. In risk management, DM's usually consider different and more often conflicting objectives under uncertain decision parameters. Hence Evidential Reasoning (ER) which is one of the latest development within Multi Criteria Decision Making (MCDM) literature and appears to be the best fit to handle uncertain information has been applied. It can model various types of qualitative and quantitative uncertainties and is developed on the basis of Dempster-Shafer evidence theory and evaluation analysis model and decision theory. A numerical examples is provided to demonstrate the implementation procedures for multi-dimensional risk management.

■ WA-13

Wednesday, 8:30-10:00 - 207

Matheuristics

Stream: Matheuristics
Invited session
Chair: Gianfranco Guastaroba

1 - A matheuristic solution approach for the optimal design of multiproduct batch plants with parallel production lines

Floor Verbiest, Trijntje Cornelissens, Johan Springael

In our research, we focus on strategic design decisions for multiproduct chemical batch plants. Since the construction of grass-root plants requires major investments, appropriate capacity assessments are needed. One of the main purposes of the batch plant design problem is to select the optimal number and size of equipment units for every production stage, out of a discrete set of available sizes, so as to minimise capital and operating costs, while taking into account design and horizon constraints. This challenging combinatorial problem has been studied extensively in literature and is generally formulated as an MINLP model that is solved exactly. However, in contrast to previous research where a single production line design problem is solved, we extend the batch plant design problem with parallel lines, each having the same number of production stages. This extended design problem involves now determining the optimal number of production lines to install and distributing the production (quantities) over these lines. As these additional decisions increase complexity significantly, the problem becomes intractable for exact solution methods. In this talk, we present a matheuristic that combines exact solution techniques with heuristics in order to solve the multi-line design problem in a reasonable amount of time. Specifically, we employ local search techniques to find good solutions for the number of lines and the product assignments.

2 - Iterative restricted space search applied to the periodic capacitated arc routing problem with continuous moves

Guilherme Vinicyus Batista, Cassius Scarpin, Jose Eduardo Pecora

The Periodic Capacitated Arc Routing Problem (PCARP) can be defined as an arc routing problem that involves a time horizon composed of more than one period. One or many vehicles must perform routes without exceeding their capacities and attend the required frequencies of each arc. We present an extension of this problem named PCARP with Continuous Moves which is applied in the inspection of railroads. Rails must be evaluated by a vehicle on regular time intervals, these evaluations can avoid possible accidents and guarantee the flow of trains. Usually, the railway networks are large, so a long-term plan must be done considering a rolling time horizon. Each car has a diary move and is not linked to any depot, the starting point of each day is the latest one visited on the previous day. An integer linear programming model is proposed and a matheuristic named Iterative Restricted Space Search (IRSS) is applied to solve it. The heuristic is based on a strategic exploration of the solution space, preliminary results show that this method is efficient bringing good results for the PCARP with Continuous Moves.

3 - Adaptive Kernel Search: A heuristic for solving mixed integer linear programs

Gianfranco Guastaroba, Martin Savelsbergh, M. Grazia Speranza

We introduce Adaptive Kernel Search (AKS), a heuristic framework for the solution of (general) Mixed Integer linear Programs (MIPs). AKS extends and enhances Kernel Search, a heuristic framework that has been shown to produce high-quality solutions for a number of specific (combinatorial) optimization problems in a short amount of time. AKS solves a sequence of carefully constructed restricted MIPs. The computational effort required to solve the first restricted MIP guides the construction of the subsequent MIPs. The restricted MIPs are constructed around a kernel, which contains the variables that are presumably positive in an optimal solution. On a set of benchmark instances, the computational results show that AKS significantly outperforms other state-of-the-art heuristics for MIPs. On an additional set of more than 100 benchmark instances from the MIPLIB2010 library, AKS compares favorably to CPLEX and is shown to be more flexible in handling the trade-off between solution quality and computing time.

■ WA-14

Wednesday, 8:30-10:00 - 305

Green logistics 2

Stream: Sustainable logistics
Invited session
Chair: *Paulo Barros Correia*
Chair: *Antoine Legrain*

1 - Smart traffic light: Parametric optimization function with Bézier curve

Rhuam Estevam, Saulo Ribeiro

The traffic flow has been chaotic in big cities for some time. But now small towns also suffer from this evil. And with it comes other problems like high emission of pollutants. Not to mention the time lost inside a vehicle. Thus, simple but effective and low-cost operational solutions need to be created and applied. This is the solution provided using the Bézier curve. This work describes the use of the Bézier curve to optimize the time of each traffic cycle, more specifically defining the optimal green time and, from this, determine the total cycle time. Currently there are three large groups that relate semaphore systems: actuated, semi-actuated and fixed time. It will be demonstrated the advantage of this system in relation to systems that are representative of each of these groups and to the traffic system most commonly used today, the SCOOT system. The Bézier curve is a function parameterized by a control polygon, where no point of the curve oscillates beyond this polygon. The points of this curve will be formed by statistical functions that calculate the ideal time for vehicles to pass, the total time spent for the passage of all vehicles in the previous phase and the estimated time for dispersion of the formed queue. The computational cost is minimal, and can be executed in fractions of seconds. After modeling, up to 74% improvement in waiting time at peak times and up to 287% increase in average track speed were found.

2 - A probabilistic model of shared transportation service addressing accessibility inequities

Mahdieh Allahviranloo, Marouane Zellou

Can we design an optimum shared transportation service such that mobility-disabled travelers are less likely to be socially excluded? We propose and test a methodology comprised of two main parts. Part I describes an innovative method to measure disparities between mobility behavior of the mobility-disabled travelers (target population) and the base population (demographically similar people in the population that are not included in the target group). We develop a set of new machine learning methods to compare and cluster spatial-temporal mobility patterns. The analysis in the dimension of time is executed using pattern segmentation and Sequence Alignment method. Comparison in the dimension of space is conducted by translating geocoded mobility patterns of the population to Scheme Characteristic Vectors, generated based on a set of geometric and shape formatting operations. A combination of machine learning techniques (KNN, Expectation Maximization, and Mixture of Gaussian models) are used to measure the disparities in the mobility behavior. Part II formulates a fleet sizing optimization problem. The objective function is to minimize the spatial-temporal gap between mobility behavior of the target group and the probabilistic patterns generated from the behavior of the base population. The model is formulated to provide demand responsive shared transportation service to the target population with probabilistic time window constraints and probabilistic demand for the ride.

3 - An on-demand multi-modal transportation system
Antoine Legrain, Connor Riley, Pascal Van Hentenryck

The combination of on-demand shared services with high-frequency transit lines holds many promises for public transportation. Such on-demand multi-modal systems improve convenience by addressing the infamous first/last mile, decrease costs by limiting capital expenses, and may significantly reduce greenhouse gas emission. This talk reviews the design and implementation of such systems in the city of Ann Arbor and, in particular the real-time routing and dispatching algorithms at the core of the operations. Comparisons with the existing systems demonstrate the performance and benefits of the proposed system.

■ WA-15

Wednesday, 8:30-10:00 - 307A

Content delivery

Stream: Graphs, telecommunication, networks (contributed)
Contributed session
Chair: *Sy-Ming Guu*

1 - Comparison between SDN and conventional networks based on multimedia services
David Salazar

In recent years, the demand of multimedia content has been growing such that current networks can not handle the amount of users requesting it. Due to this problem, there is a new networking approach called Software Defined Networking (SDN), which aims to solve the actual problems for conventional networks in terms of multimedia services. SDN separates the control layer from a device, and rises it to a superior layer in order to control the behavior of all components of a network. Therefore the objective of this paper is to make a performance evaluation for SDN and compare it with conventional networks to show which network is the best for multimedia content and which provides the best quality in terms of video on demand (VoD). In order to do that, a topology with three different SDN controllers is implemented: POX, OpenDayLight (ODL) and RYU, and compared against an implementation based on conventional networks. A performance analysis is made with the objective of measure and compare the QoS parameters of each network when a user reproduce a YouTube video. Our results show that SDN and RYU controller could be the best cases for VoD in terms of throughput, RTT and packet loss.

2 - Protective device and isolating switch allocation for distribution reliability optimization with tie switches and distributed generators
Jia Guo

In a distribution network, the allocation of protective devices, sectionalizers and isolating switches can be formulated as an optimization problem aiming to minimize the total cost. In this paper, the protective devices (reclosers and fuses) can detect faults automatically; a sectionalizer cuts transmission closer to the fault; isolating switches, tie switches, and distributed generators can quickly restore downstream loss. Network reliability improves as more devices are installed. However, the installation cost of devices is a trade-off. The optimization problem formulation is a mixed integer linear program (MILP), which can obtain a global optimal solution in a reasonable amount of time, even for large systems.

3 - Broadcast domination in permutation graphs
Eunjeong Yi

Broadcast domination models the idea of covering a network of cities by transmitters of varying powers while minimizing the total cost of the transmitters used to achieve full coverage. To be exact, let G be a connected graph of order at least two with vertex set V(G). Let d(x,y), e(v), and diam(G) denote the length of a shortest x-y path in G, the eccentricity of a vertex v in G, and the diameter of G, respectively. A function f on V(G) with values in 0,1,. . . , diam(G) is called a broadcast if f(v) is no greater than e(v) for each vertex v in G. A broadcast f is called a dominating broadcast of G if, for each vertex u in G, there exists a vertex w in G such that f(w) is positive and no less than d(u,w). For any function f on G, let f(V(G)) denote the sum of the values of f on V(G). The broadcast domination number of G is the minimum of f(V(G)), as f varies over all dominating broadcasts of G. Let A and B be two disjoint copies of a graph G, and let p be a bijection from V(A) to V(B). Then the permutation graph Gp has as its vertex set the union of the vertices of A and B, and Gp has as its edge set the union of the edge sets of A and B, together with an edge a,b whenever p(a)=b. In this talk, we discuss some results on broadcast domination in permutation graphs.

4 - Finding an optimal data transmission in BitTorrent-like peer-to-peer file sharing system
Sy-Ming Guu

Finding an optimal data transmission in BitTorrent-like peer-to-peer file sharing systems has been modeled by an optimization problem subject to a set of addition-min typed constraints. Depending on the objective function which reflects the managerial consideration, searching algorithms or linear program approaches have been proposed in the literature. In this presentation, we will show how to find an optimal solution for the system congestion yet still with other managerial contributions.

■ WA-16

Wednesday, 8:30-10:00 - 308A

Decision theory

Stream: Decision support systems
Invited session
Chair: *Shaofeng Liu*

1 - Complexity, decision support and human behaviour
Winnie Pelser

Problems that face policy makers are often complex and need predictions within uncertain futures that concern a wide rangecof possible stakeholders. Decision support for such situations is vital and this talk will explore possible options and approaches. Complex problems can not necessary be solved with conventional methods alone. In order for any approach to complex problems to be suitable, it must be properly defined, taking different perspectives of stakeholders into account.

2 - R&D project selection using recent advances in multi-criteria ordinal classification methods
Edy López Cervantes, Eduardo René Fernández González

Funding R&D projects is perhaps the most important task faced by public organizations, universities and research centers in charge of promoting science and technology in different countries. However, most popular ways to solve this decision problem are based on too simple decision models and weak heuristics, often using a rough weighted-sum value function, in which weights and criteria are partially arbitrary. Distributing the funds following the weighted-sum values does not guarantee the best portfolio This paper a new methodology is presented to assist managers of those organizations to nominate the best projects. The quality of a project is modeled by many criteria reflecting scientific and technologic impact, success probability, impact on other organizational criteria, and project cost. A project to be evaluated is compared to several boundary reference projects in order to determine whether the applicant project is, at least, acceptable. ELECTRE TRI-nB, a new multi-criteria ordinal classification method, is used for this aim This methodology propounds: a) a measure of the global impact and probability of success as main attributes to access the quality of a R&D project through its certainty equivalent; b) a way to represent preferences and beliefs from the managers; c) an approach to take into account that information in the evaluation; d) a way to update the beliefs of the managers In some examples of real size our proposal clearly outperforms traditional methods

3 - Aggregating opinions on ordinal proximities among linguistic terms of qualitative scales
José Luis García-Lapresta, Raquel Gonzalez del Pozo, David Perez-Roman

Ordered qualitative scales are frequently used in real problems for dealing with the vagueness of human beings when evaluating different issues. Usually, it is implicitly assumed that these qualitative scales are uniform, in the sense that the psychological proximity between every pair of consecutive terms of the scale is perceived as identical. However, some qualitative scales are not uniform. For instance, there is empirical evidence that the qualitative scale reject, major revision, minor revision, accept used for evaluating papers by some scientific journals is non-uniform. In order to deal with non-uniform qualitative scales, Garcia-Lapresta and Perez-Roman (Applied Soft Computing 35, pp. 864-872, 2015) introduced the notion of ordinal proximity measure, and psychological proximities among linguistic terms of ordered qualitative scales were measured in a purely ordinal way. In this contribution, we focus on how to aggregate the opinions of several experts on the proximities among the linguistic terms of an ordered qualitative scale. We provide some aggregation procedures that fall within the framework of judgment aggregation. In particular, we introduce an algorithm that constructs an ordinal proximity measure for each expert that depends on how they perceive the proximities among some terms of the scale. Finally, we provide an appropriate distance-based aggregation procedure to determine a collective ordinal proximity measure that represents experts' opinions.

■ WA-17

Wednesday, 8:30-10:00 - 309A

Nonlinear optimization with uncertainties 1

Stream: Nonlinear optimization with uncertainties
Invited session
Chair: *Natasa Krejic*

1 - Some complexity results with high-order regularization
José Mario Martínez

Recent theory on nonlinear optimization is generally based on complexity results. These results state upper bounds of the computer work that is necessary to achieve a given precision. Subproblem regularization is a key tool for obtaining the best complexity results available. By means of cubic regularization it is possible to define practical algorithms that allow Newton-like methods to achieve optimal complexity results. However, higher order regularization may be employed in some cases and may also give rise to efficient methods. We will analyze situations in which constraints are present and situations in which the evaluation of the objective function is subject to errors.

2 - Relaxed Peaceman-Rachford splitting method on the sum of two maximal strongly monotone operators: Convergence study
Chee Khian Sim, Renato D.C. Monteiro

We consider the monotone inclusion problem on finding the zeroes to the sum of two maximal strongly monotone operators and the relaxed Peaceman-Rachford splitting method is used to solve the problem. We provide convergence, pointwise convergence rate and ergodic convergence rate results on iterates generated by the method to solve the monotone inclusion problem. An example is further discussed that shows nonconvergence of the method when the relaxation parameter is beyond some value. Convergence analysis is based on the (non-Euclidean) hybrid proximal extragradient method.

3 - Distributed spectral-like gradient method
Natasa Krejic, Dragana Bajovic, Dusan Jakovetic, Natasa Krklec Jerinkić

Since the seminal work by Barzilai and Borwein in 1988, and Raydan in 1990, spectral gradient methods continue to receive significant attention, especially due to their excellent numerical performance on various large scale applications. However, to date, they have not been sufficiently explored in the context of distributed optimization. In this work, we consider unconstrained distributed optimization problems where N agents constitute an arbitrary connected network and collaboratively minimize the sum of their local convex cost functions. In this setting, we develop distributed gradient methods where agents' step-sizes are designed according to the rules akin to those in spectral gradient methods. Numerical performance of the proposed distributed methods is illustrated on several application examples.

4 - Fast and robust self-localization of networked agents
Claudia Soares, Joao Gomes

Networks of agents typically rely on known node positions even if the main goal of the network is not localization. A network of agents may comprise a large set of miniature, low cost, low power autonomous sensing nodes. In this scenario it is generally unsuitable to accurately deploy all nodes in a predefined location within the network operation area. GPS is also discarded as an option for indoor applications or due to cost and energy consumption constraints. The approaches pursuing distributed and scalable solutions develop approximations or tackle the maximum-likelihood nonconvex problem, sometimes combining both approaches. With the growing network sizes and constraints in energy expenditure and computation power, the need for simple, fast, and distributed algorithms for network localization spurred the work presented on this abstract. We present simple, fast and convergent synchronous and asynchronous relaxation methods. From the analysis of the problem, we uncover key properties which allow a synchronous time, distributed gradient algorithm with an optimal convergence rate. We also present an asynchronous randomized method, more suited for unstructured and large scale networks. We prove not only almost sure convergence of the cost value, but also almost sure convergence to a point. This stronger convergence result has a significant impact in real time applications because nodes can safely probe the amount of change in the estimates to stop computing.

■ WA-19

Wednesday, 8:30-10:00 - 2102AB

Lot-sizing and related topics

Stream: Lot-sizing and related topics
Invited session
Chair: *Bernardo Almada-Lobo*
Chair: *Christian Almeder*
Chair: *Stéphane Dauzere-Peres*
Chair: *Raf Jans*

1 - Consumer stockpiling behavior in a changing economy: Implications for retail inventory management
Xiaodan Pan, Benny Mantin, Martin Dresner

We study the impacts of economic shocks on stockpiling behavior, distinguishing between stockpiling and non-stockpiling consumer segments. A contracting economy may induce consumers to restrain their weekly expenditures, even when promotions are offered. Moreover, consumers may be more attentive to promotions, thus increasing purchases during promotional periods. Using a sample retail channel and a panel of households between 2007 and 2009, we find that the consumption rates of both stockpiler and non-stockpiler segments decrease when the economy contracts. Further, consumers are more likely to behave as stockpilers during contraction periods than during expansion periods. From a managerial perspective, these changing patterns of consumer stockpiling behavior introduce challenges to retail inventory management. As the economy contracts, promotional inventory has to be corrected downwards to capture decreases in overall demand, but also adjusted upwards to account for higher propensity to stockpile. Moreover, regional differences add additional complexity to the managers' tasks. These findings highlight the importance of carefully monitoring the economic environment to assess stockpiling behavior when managing inventories.

2 - An effective tabu search algorithm to optimize a multi-product multi-constraint EOQ model

Hamidreza Mozaffari Gilani, Arezoo Bolourchi Hossein Zadeh, Ashraf Moharrami, Siamak Ghodsi Rad, Mohammadreza Dolatirik, Mahyar Amir Abbasi

This research formulates a multi-product economic order quantity (EOQ) problem with an order-quantity-dependent permissible delay in Payment. It should be mentioned that, in business transactions, sometimes customers are allowed to pay in a grace period, i.e., permissible delay in payment occurs. The amount of discount and the length of the grace period depend on the order quantity and all the costs increase by an inflation rate. Moreover, the shortage is backlogged and the limited warehouse space leads to a constraint for storage. In order to make the model more applicable to real-world production and inventory control problems, we expand this model by assuming a multi-product economic order quantity problem with limited warehouse-space and capital limitation. Thus, the problem of this paper is a constrained nonlinear-integer program (NIP) and we propose a Tabu Search Algorithm to find a near-optimum solution with the objective of minimizing the total cost of the supply chain. To define the problem, we consider a company as a retailer that works with a supplier. The company stores several products replenished by the supplier to satisfy its customers' needs. At the end, numerical examples in three categories (small, medium and large size) were presented to demonstrate the application of the proposed methodology. The results revealed that the proposed procedure was able to find better and nearer optimal solutions because they were very close to their lower bounds.

■ WA-20

Wednesday, 8:30-10:00 - 2103

Theory and applications of optimization under uncertainty

Stream: Stochastic optimization
Invited session
Chair: *Kartikey Sharma*

1 - Modelling delay dissatisfactions in appointment scheduling

Shuming Wang

We consider a problem of appointment sequencing and scheduling with uncertain service times and no-shows. Service users experience dissatisfaction due to delays in their appointment time, and we propose a Tolerance Aware Delay (TAD) index to quantify the user's dissatisfaction by incorporating their delay tolerance level. We show several advantages of the proposed index compared to other performance measures, and also its computational attractiveness in the sense that it is jointly convex in the delay and tolerance. We develop two appointment optimization models using the TAD index, one based on sample average approximation, and the other based only on the available mean, support and covariance bounds of the service times, with the objective of minimizing the total delay dissatisfaction of users. The corresponding optimization models are shown to be in the formats of a mixed integer linear program and mixed-integer second-order conic program, respectively, which can be evaluated efficiently using off-the-shelf solvers. Numerical experiments demonstrate the performance and insights of using the proposed TAD index models in appointment problems under uncertainty.

2 - Ellipsoidal methods for adaptive choice-based conjoint analysis

Denis Saure, Juan Pablo Vielma

Adaptive choice-based conjoint analysis aim at minimizing the uncertainty associated with preference parameters (e.g. partworths). Bayesian approaches to conjoint analysis quantify this uncertainty with a multivariate distribution that is updated after the respondent answers. Unfortunately, this update requires multidimensional integration, which effectively reduces the adaptive selection of questions to impractical enumeration. An alternative approach is the polyhedral method by Toubia et al. (2004), which quantifies the uncertainty through a (convex) polyhedron. The approach has a simple geometric interpretation, and allows for quick uncertainty-region updates and effective optimization-based heuristics for adaptive question selection. However, its performance deteriorates with high error rates. We show how, by using ellipsoidal uncertainty sets, one can include respondent error and develop a purely geometric approach that is as intuitive as the polyhedral approach, but nearly matches what a Bayesian approach would do. The approach extends the effectiveness of the polyhedral approach to the high response error setting and provides a geometric interpretation of Bayesian approaches. In addition, it allows designing practical, near-optimal question selection methods. These methods are based on a precise relation between the D-efficiency criterion and heuristic guidelines promoted in extant work. We show the superiority of the method through exhaustive numerical experiments.

3 - Robust optimization with decision dependent uncertainty sets

Kartikey Sharma, Omid Nohadani

Robust optimization is increasingly used to solve multistage optimization problems where the uncertainty set is typically modeled to be fixed. However in many cases, these sets can be influenced by decision variables. We present a two-period robust optimization approach in which future uncertainty sets can be affected by the decisions made in the first stage. We illustrate the advantages of this model on a shortest path problem with uncertain arc lengths.

■ WA-21

Wednesday, 8:30-10:00 - 2104A

Cutting and Packing 1

Stream: Cutting and packing
Invited session
Chair: *José Fernando Gonçalves*

1 - Primal-dual algorithms for the constrained two-dimensional guillotine cutting problem

Eduardo Uchoa, André Velasco

The Two-dimensional Guillotine Cutting Problem (TGCP) consists in determining the most valuable way of cutting a rectangular object, using only orthogonal guillotine cuts, in order to produce a number of smaller rectangular pieces that are copies of distinct items with given dimensions and individual value. The Constrained TGCP is the variant where each item also has a given demand, the maximum number of copies of an item that can be cut, which makes the problem strongly NP-hard and much harder in practice. This work addresses CTGCP in two cases: with and without item rotation. There are no restrictions on the number of cutting stages. It proposes a primal-dual algorithm, that yields a feasible solutions together with an upper bound on the value of the optimal solution, composed by the following original components: (1) An improvement of the pure primal method by [Velasco and

Uchoa 2014], based on Reactive GRASP; (2) Algorithm X, based on integer programming, provably capable of obtaining the best possible upper bounds with the dynamic programming state space relaxation proposed by [Christofides and Hadjiconstantinou 1995]; (3) Algorithm X2, a generalization of X that uses two-dimensional weights to obtain even stronger upper bounds; (4) The X2H algorithm, an adaptation of X2 to transform it into a primal heuristic. The overall algorithm was tested in 1,000 instances from the literature and could consistently find high quality solutions, often certificated to be optimal.

2 - An efficient local search algorithm for nesting problems of rasterized shapes
Shunji Umetani, Shohei Murakami, Hiroshi Morita

We focus on the nesting problems of rasterized shapes where a given set of arbitrary shaped items represented in raster format should be packed into a rectangular container without overlap. The raster models enable us to check overlaps without any exception handling arising from geometric issues, while they often need much memory and computational effort as their accuracy is improved. We develop an efficient algorithm to check overlaps using a compact representation of rasterized shapes called the scanline representation, which reduces the complexity of rasterized shapes by merging the pixels in each row into strips with unit width. Based on this, we develop a local search algorithm that applies a line search in horizontal and vertical directions alternately. Computational results for well-known benchmark instances show that our algorithm obtains good layouts of items represented in high resolution raster image within a reasonable computation time.

3 - A multi-period irregular bin packing problem with usable leftovers.
Julia Bennell, Ranga P. Abeysooriya, Antonio Martinez Sykora

Output minimisation cutting and packing problems seek to make a geometric assignment of small items to large items where all the items are known in advance. As a result, a solution assumes that all items are cut in the same production period or the production period does not matter. In this paper we consider a multi-period problem where the demand is not available, or permitted to be cut, until a designated production period. While this could be solved as multiple bin packing problems, when off-cuts of material can be used in the following periods, there is a dependency between cutting plans. Moreover, when the storage and setup cost are considered, then the benefit to keeping usable leftovers is more complex than simply minimising the use of material. Finally, when the material can be procured in a range of standard size stock sheets, the selection of the standard sizes also affects the optimisation. The presentation will explore these questions for the irregular shape bin packing problem. Metal cutting industries would be a typical example of this. We will present some details of our algorithm for packing irregular shaped pieces over heterogeneous bins and provide details of the data and implementation for the multi-period problem. We test our model over a range of policies that may be adopted by industry and examine the cost sensitivity over these scenarios. Finally, we will draw some general conclusions on the interplay between material, inventory and productions costs.

4 - A novel NLIP formulation and a BRKGA based approach for a production and cutting problem in the home-textile industry
José Fernando Gonçalves

This paper addresses a problem in the home-textile industry. Given a set of orders of rectangles of fabric the problem consists of determining the lengths and widths of a set of large rectangles of fabric to be produced and the corresponding cutting patterns. The objective is to minimize the total quantity of fabric necessary to satisfy all orders. We introduce a novel NLIP formulation and a hybrid approach combining a heuristic procedure with a biased random-key genetic algorithm (BRKGA). The approaches are tested on a set of random generated instances. The experimental results validate the quality of the solutions and the effectiveness of the proposed BRKGA algorithm. Supported by Project "NORTE-01-0145-FEDER-000020" financed by the North Portugal Regional Operational Programme (NORTE 2020), under the PORTUGAL 2020 Partnership Agreement, and through the European Regional Development Fund (ERDF).

■ WA-22

Wednesday, 8:30-10:00 - 2104B

Applications of constraint programming

Stream: Constraint programming
Invited session
Chair: Gilles Pesant

1 - Solving the wedding seating problem by constraint programming
Philippe Olivier, Gilles Pesant, Andrea Lodi

The wedding seating problem consists in assigning guests to tables in such a way as to seat friends together and foes apart, while simultaneously keeping the tables balanced. We present a constraint programming model of this problem and compare it empirically to other computational approaches.

2 - Online algorithms for the linear tape scheduling problem
Carlos Cardonha, Lucas Villa Real

Even in today's world of increasingly faster storage technologies, magnetic tapes continue to play an essential role in the market. Yet, they are often overlooked in the literature, despite the many changes made to the underlying tape architecture since they were conceived. In this talk, we present the linear tape scheduling problem (LTSP), which aims to identify scheduling strategies for read and write operations in single-tracked magnetic tapes that minimize the overall response times for read requests. Structurally, LTSP has many similarities with versions of the Travelling Repairman Problem and of the Dial-a-Ride Problem restricted to the real line. We investigate several properties of LTSP and show how they can be explored in the design of algorithms for the online version of the problem. From the theoretical standpoint, we present a 3-approximation for the offline LTSP and show that the online version of the problem does not admit c-approximation algorithms for any constant c. Computational experiments show that the resulting strategies deliver very satisfactory scheduling plans, which in most cases are clearly superior (potentially differing by one order of magnitude) to those produced by a strategy currently used in the industry.

3 - A logic-based Benders approach to home health care delivery
Ryo Kimura, Aliza Heching, John Hooker

We propose an exact optimization method for home healthcare delivery that relies on logic-based Benders decomposition (LBBD). The objective is to match patients with healthcare aides and schedule multiple home visits over a given time horizon, so as to maximize the number of patients served while taking into account patient requirements, travel time, and scheduling constraints. Unlike classical Benders methods, LBBD allows us to exploit a natural decomposition of the problem into a master problem, solved by mixed integer programming, and a subproblem that decouples into small scheduling problems, solved by constraint programming. We report computational results based on data obtained from a major home hospice care provider. We find that LBBD is far superior to mixed integer programming if there are a limited number of temporal dependencies between visits. We also find that LBBD is a more robust solution method for this problem than branch and check, a variant of LBBD.

4 - Balancing nursing workload by constraint programming
Gilles Pesant

Nursing workload in hospitals has an impact on the quality of care and on job satisfaction. Understandably there has been much recent research on improving the staffing and nurse-patient assignment decisions in increasingly realistic settings. On a version of the nurse-patient assignment problem given a fixed staffing of neonatal intensive care units, constraint programming (CP) was shown to perform better than competing optimization methods. In this paper we take advantage of recent improvements to the CP approach to solve the integrated problem of staffing and nurse-patient assignment. We then consider a more difficult but also more realistic version of the problem in which patients are categorized into a small number of types and the workload associated with each type is nurse-dependent.

■ WA-23

Wednesday, 8:30-10:00 - 2105

Demand driven public transportation modeling

Stream: Optimization for public transport
Invited session
Chair: *Virginie Lurkin*
Chair: *Michel Bierlaire*

1 - Integrating supply and demand within the framework of mixed integer linear problems
Meritxell Pacheco Paneque, Shadi Sharif Azadeh, Michel Bierlaire, Bernard Gendron

The integration of customer behavioral models in optimization provides a better understanding of the preferences of clients (the demand) to policy makers while planning for their systems (the supply). On one hand, these preferences are formalized with discrete choice models, which are the state-of-the-art for the mathematical modeling of demand. On the other hand, the optimization models that are considered to design and configure a system are associated with (mixed) integer linear problems (MILP). The complexity of discrete choice models leads to mathematical formulations that are highly nonlinear and nonconvex in the variables of interest, and are therefore difficult to be included in MILP. In this research, we present a general framework that overcomes these limitations and is able to integrate advanced discrete choice models in MILP. Since the formulation has designed to be linear, the price to pay is its high dimension, which results in a computationally expensive problem. To address this issue, and given the underlying structure of the model, decomposition techniques can be employed. More precisely, Lagrangian decomposition can be applied since there are two subproblems with common variables: one concerning the user and another concerning the operator. In the former, the user has to perform a decision based on what the operator is offering, whereas in the latter, the operator needs to decide about the features of the supply to make it attractive to the users.

2 - Short-term demand estimation for ride-hailing systems using machine learning approaches
Melvin Wong, Ismaïl Saadi, Bilal Farooq, Jacques Teller, Mario Cools

In this paper, we present various implementations of machine learning approaches for estimating the short-term demand for on-demand ride-hailing systems. We propose a spatio-temporal estimation of the demand that is a function of variable effects related to traffic, pricing and weather conditions. With respect to the methodology, a single decision regression tree, a set of bootstrap-aggregated (bagged) decision trees and random forests for regression have been set up and systematically compared using various statistics, e.g. R-square, Mean Square Error (MSE), and slope. To better assess the quality of the models, they have been tested on a real case study DiDi on-demand ride-hailing service in China. In the current study, 199,584 time-slots describing the spatio-temporal ride-hailing demand has been extracted with an aggregated-time interval of 10 mins. All the methods are trained and validated on the basis of two independent datasets. The results reveal that random forests provide the best prediction accuracy while avoiding the risk of overfitting, followed by the set of bootstrap-aggregated (bagged) decision trees and the single decision tree. To the best of our knowledge, no studies have investigated the short-term ride-hailing demand based on machine learning techniques using a large-scale dataset.

3 - Forward-looking smart mobility systems
Xiang Song, Bilge Atasoy, Moshe Ben-Akiva

Smart mobility systems are emerging to serve the increasing heterogeneous travelers' needs for public and private services. In this paper, we focus on optimal operations of such systems through personalized menu optimization which can offer mobility users a personalized menu including various travel options such as public transit, shared taxi, and taxi. These systems have to deal with the trade-offs of obtaining high immediate rewards such as revenue and energy saving versus saving inventory for future demand. We propose a solution based on approximation of dynamic program that can resolve this trade-off. We implement such solution in the smart mobility systems including Tripod, an incentivized sustainable travel planner which incentivizes travelers to green transportation modes such as public transit through token allocation, and FMOD, flexible mobility on demand which offers personalized mobility solutions by allocating same type of vehicle to different levels of services including taxi, shared taxi and mini-bus. We show that the performances of these smart mobility systems are improved under various conditions through simulation experiments.

4 - Innovative intercity transport mode: Application of choice preference integrated with attributes nonattendance
Anae Sobhani, Bilal Farooq

A new intercity mode, Train Hotel will offer leisurely and comfortable overnight rides between Montreal and New York/Boston, with private bedroom and access to a lounge with live music and chief on-board. This paper investigates different aspects of introducing this innovative mode in order to improve the efficiency of public interurban transport systems. We aim to incorporate passengers' preferences into estimating the real and potential demand for the proposed mode by considering sets of exogenous and conceptual attributes that some individual attends to evaluate choices, and analyse how various levels of each factor are considered in this course jointly. That is, we tend to integrate multiple decision process strategies (attribute nonattendance and value learning) with disaggregated and perceptual attributes while taking into account unobserved heterogeneity in decision making by adopting a revealed and stated preference survey which provides adequate data with focus on an individual's choice set, and employing the logit and latent class (probabilistic decision process) models for behaviour analysis while focusing on the effects of repetitive choice sets within each other. Initial results show that combining different qualitative and quantitative variables, and considering multiple heuristics enhances the model estimations and performance statistically. Hence, this will enrich planners' and policy makers' understanding of individual preference.

■ WA-24

Wednesday, 8:30-10:00 - 301A

Emergency response optimization

Stream: CORS SIG on healthcare
Invited session
Chair: *Justin Boutilier*
Chair: *Christopher Sun*

1 - Rise and shock: Optimal defibrillator placement in a high-rise building
Timothy Chan

Out-of-hospital cardiac arrests (OHCAs) in high-rise buildings experience lower survival and longer delays until paramedic arrival. Use of publicly accessible automated external defibrillators (AED) can improve survival, but "vertical" placement has not been studied before. We aim to determine whether elevator-based or lobby-based AED placement results in shorter vertical distance travelled ("response distance") to OHCAs in a high-rise building. To address this question, we develop a model of a single-elevator, n-floor high-rise building, modeling OHCA occurrences using floor-specific Poisson processes. We derive a simple and intuitive equation relating n and the relative risk between ground-floor OHCA to above-ground-floor OHCA that completely characterizes the optimal decision when the objective is to minimize average response distance.

2 - How load affects service times in emergency medical service
Armann Ingolfsson

We apply a general framework to analyze the influence of system load on service times in queueing systems to EMS systems. The framework unifies previous results and ties them to possible future studies to help empirical and analytical researchers to investigate and model the ways in which load impacts service times. We describe several mechanisms through which load induces behaviors in the servers, the users, or the network that cause the work content or the service speed to change. We test hypotheses related to the mechanisms using data from the Calgary EMS system. We discuss the implications our framework for empirical research on EMS operations.

3 - Optimizing public defibrillator deployment to overcome spatial and temporal accessibility barriers
Christopher Sun, Timothy Chan

Immediate access to an automated external defibrillator (AED) increases the chance of survival from out-of-hospital cardiac arrest (OHCA). Current deployment usually considers spatial AED access, assuming AEDs are available 24 hours a day. We developed an optimization model for AED deployment, accounting for spatial and temporal accessibility, to evaluate OHCA coverage compared to a deployment based on spatial accessibility alone. Methods: We identified all non-traumatic public-location OHCAs in Toronto, Canada (2006-2014) from the Regional RescuNET OHCA Epistry and obtained a list of registered AEDs (2015) from Toronto Paramedic Services. We quantified coverage loss of registered AEDs due to limited temporal access. We then developed a spatiotemporal optimization model that determines AED locations to maximize the number of OHCAs that occurred within 100m of a location when the location was open. We computed the coverage gain between the spatiotemporal model and a spatial-only model on using 10-fold cross-validation. Statistical analyses were conducted using 2 and McNemar's tests. We identified 2440 atraumatic public OHCAs and 737 registered AED locations. The registered AEDs had a coverage loss of 21.5% (P<0.001); 354 of 451 OHCAs were covered when accounting for temporal information. Using the spatiotemporal model to optimize AED deployment, a 25.3% relative increase in OHCA coverage was achieved over the spatial-only model (P<0.001).

4 - Optimizing a drone network to deliver automated external defibrillators
Justin Boutilier, Timothy Chan

Public access defibrillation programs can improve survival after out-of-hospital cardiac arrest (OHCA), but automated external defibrillators (AEDs) are rarely available for bystander use at the scene. Drones are an emerging technology that can deliver an AED to the scene of an OHCA. We develop a mathematical approach that determines the number and location of drone bases, along with the number of the drones required at each base, to meet any AED arrival time goal. We applied our model to 53,702 OHCAs that occurred in the eight regions of the Toronto Regional RescuNET between January 1st 2006 and December 31st 2014. Our primary analysis quantified the drone network size required to deliver an AED one, two, or three minutes faster than historical median 911 response times for each region independently. A secondary analysis quantified the reduction in drone resources required if RescuNET was treated as one large coordinated region. The region-specific analysis determined that 81 bases and 100 drones would be required to deliver an AED ahead of median 911 response times by three minutes. In the most urban region, the 90th percentile of the AED arrival time was reduced by 6 minutes and 43 seconds relative to historical 911 response times in the region. In the most rural region, the 90th percentile was reduced by 10 minutes and 34 seconds. A single coordinated drone network across all regions required 39.5% fewer bases and 30.0% fewer drones to achieve similar AED delivery times.

■ WA-25

Wednesday, 8:30-10:00 - 301B

Game theory and optimization for health and life sciences 3

Stream: Optimization, analytics and game theory for health and life sciences
Invited session
Chair: *Gerhard-Wilhelm Weber*
Chair: *Milagros Baldemor*
Chair: *Preston White*

1 - Cadaver driven chains in kidney exchange program
Utkarsh Verma, Viswanath Billa, Narayan Rangaraj, Deepa Usulumarty

Kidney transplant happens via either a living donor or from a cadaveric transplant. Often, patients may have a living donor who is not compatible. For such incompatible pairs, kidney exchange programs (KEP) have been developed, where incompatible donor patient (DP) pairs exchange their donor's kidney via cycles or chains to get a compatible kidney for the patient. Another pathway for kidney transplants is via cadaveric donation. When a cadaveric donor becomes available, both kidneys are given to wait list patients according to a ranked list and compatibility. Our idea is to merge both these transplant processes and create cadaver driven chains from a registry containing both incompatible DP pairs and cadaveric wait list patients. Since a cadaveric donor has two kidneys, one of them can be used to create a chain where the kidney is given to paired patient and the intended donor will donate it to some other pair and last donor of the chain will donate a kidney to a patient in cadaveric wait list. Thus there is no loss to the wait list patients and few paired patients will get a compatible kidney. An Integer programming model for cadaver driven chains is created and simulations are done on representative data sets. The results shows that significant gains can be achieved via this merged process in terms of number of transplants and reduced waiting times for a compatible kidney.

2 - Impulsive control in multi-strain epidemic model
Yaroslavna Pankratova, Elena Gubar, Vladislav Taynitskiy

Different strains of influenza viruses spread in human populations during every season of epidemics. As the infected population size increases, the virus can mutate itself and grow in its strength. Hence it is important to protect a population from several heterogeneous viruses, which can propagate at the same time. We model the dynamics of propagation of the viruses with different strength in the population when both types can coexist in one host organism. We depart from the traditional continuous monitoring and control paradigm of epidemics and investigate the impulse control problems where control can be only applied at a finite number of times. It is possible to use a series of impulse control actions which can be applied in certain time moments or adhere to the time interval. Based on the continuous model we present a complex model which includes the system of differential equation to describe the behavior of viruses and discrete system of impulses.

We formulate an optimal control problem that seeks to minimize the total system cost that includes the economic value of treatment and resources required by countermeasures. We derived the conditions for the eradication of epidemics for different cases of protection policies and compare costs and effectiveness of impulse actions and standard method of resistance.

3 - Appointment rescheduling using geospatial data: A notional simulation
Preston White, William Scherer, Peter Whitehead

The U.S. Veterans Health Administration continues to experience significant delays in scheduling patient appointments. These delays jeopardize patient outcomes and compound operating inefficiencies by inducing exceptionally high no-show rates. We propose a voluntary program that employs a mobile-phone application to monitor a patient's geographic location during a time window immediately preceding an appointment. Each patient is assigned a prior probability of timely arrival based on factors such as the patient's demographic profile, purpose of the visit, prior appointment history, and scheduling delay time. A patient's arrival probability is updated at regular intervals during the monitoring window, based on the travel time to the clinic from the patient's current location and the time remaining before the appointment. If the arrival probably falls below a specified threshold, the appointment is reassigned to another patient drawn from a predetermined pool of standbys. We demonstrate the efficacy of this rescheduling concept using a discrete-event simulation to determine the sensitivity of performance measures to scheduling algorithm parameters. Parameters include the bounds of the monitoring window and the rescheduling threshold probability. Key performance measures include the utilization of schedule slots, the percent of patients erroneously rescheduled, the waiting times of these patients, and overall rescheduling and recovery rates.

4 - Mergers and acquisitions in blood banking systems: A supply chain network approach
Anna Nagurney, Amir Masoumi, Min Yu

In this talk, we develop a methodological framework for the quantifiable assessment of total cost efficiency (synergy) associated with a merger or acquisition in the blood banking industry, which is experiencing a volatile environment, as well as measures capturing the expected supply shortage and surplus. The network optimization pre- and post-merger models handle perishability of the life-saving product of blood, include both operational and discarding costs of waste, capture the uncertainty associated with the demand points, as well as the expected total blood supply shortage cost and the total discarding cost at demand points. The models incorporate capacities on the links and their solution yields the optimal link flows plus frequencies of activities associated with blood collection, shipment, testing and processing, storage, and distribution. The proposed computational procedure is then applied to a large-scale example inspired by a pending merger in the real-world in both status quo and disaster scenarios to demonstrate the generality of the framework.

■ WA-26

Wednesday, 8:30-10:00 - 302A

Optimization in power systems

Stream: Equilibrium problems in energy
Invited session
Chair: *Anya Castillo*
Chair: *Cristiana Lara*

1 - MINLP formulation and solution strategies for network-constrained unit commitment with nonlinear AC models
Carl Laird, Jianfeng Liu, Anya Castillo, Jean-Paul Watson

Traditional unit-commitment formulations in power transmission systems rely on a linearized version of the AC power flow equations. The solution from this linearized model is not guaranteed to be feasibly (or optimal) for the actual AC system. In this presentation, we develop a globally optimal solution strategy for the unit-commitment problem with nonlinear AC transmission models. This approach (built in the Pyomo optimization framework) is an outer-approximation method where an MIQP relaxation (based on an SOCP formulation) is used to find provable lower bounds and candidate integer solutions, and an NLP formulation is used to find upper bounds. This approach is shown to be computationally efficient for ACOPF and NCUC.

2 - Scenario-based decomposition for parallel solution of the contingency-constrained ACOPF
Jean-Paul Watson, Carl Laird, Anya Castillo

We present a nonlinear stochastic programming formulation for a large-scale contingency-constrained optimal power flow problem. Using a rectangular IV formulation to model AC power flow in the transmission network, we construct a nonlinear, multi-scenario optimization formulation where each scenario considers nominal operation followed by a failure an individual transmission element. Given the number of potential failures in the network, these problems are very large; yet need to be solved rapidly. In this paper, we demonstrate that this multi-scenario problem can be solved quickly using a parallel decomposition approach based on progressive hedging and nonlinear interior-point methods. Parallel and serial timing results are shown using test cases from Matpower, a MATLAB-based framework for power flow analysis.

3 - MILP formulation and nested decomposition algorithm for planning of electric power infrastructures
Cristiana Lara, Ignacio Grossmann

The increasing contribution of intermittent renewable generation to the power grid poses new challenges for power systems planning models, such as the multi-scale integration of detailed operating decisions in the hourly level with investment decisions over a few decades. In this paper we propose mixed-integer linear programming (MILP) model to optimize the planning of generation expansion required to meet the projected load demand over the next few decades while taking into account detailed operational constraints and the variability and intermittency of renewable generation sources. In order to mitigate the combinatorial explosion of having hourly decisions over a few decades, some judicious modelling strategies are taken, such as time sampling and generator clustering. In order to optimize larger instances, we propose a decomposition algorithm based on Nested Benders Decomposition for mixed-integer problems. This model targets large-scale multi-period problems and allows us to investigate the impact of different lengths of representative periods per season in the planning strategy. The proposed formulation and algorithm are applied to a case study in the region managed by the Electric Reliability Council of Texas (ERCOT) for a 30 year planning horizon, and the results for the different lengths of representative periods is compared.

4 - Global Solution Methods for Globally Optimal Energy Storage System (ESS) Integration
Anya Castillo, Dennice Gayme

This presentation focuses on global solution techniques for solving OPF models for optimal storage integration. The global solution techniques applied in these studies reformulate non-convex problems as convex relaxations of the original problems. These relaxations are exact under certain conditions. Although local optima of the OPF have not been reported in practice, global solution techniques can guarantee no duality gap, which allows more rigorous analysis of the OPF problem as it relates to spot pricing theory.

■ WA-27

Wednesday, 8:30-10:00 - 302B

Behavioural OR and operations management

Stream: Behavioural OR
Invited session
Chair: Ilkka Leppanen

1 - Consultant interventions and behavioural change in supply chain forecasting

Fotios Petropoulos, Dilek Onkal, Konstantinos Nikolopoulos

It has been empirically shown that a simple combination of the system (statistical) forecast and its judgmentally revised counterpart (expert forecast) can lead to a more accurate final forecast. However, it is argued that a further adjustment of the expert adjusted forecast would ultimately lead to a long-term change of forecasters' behaviour. The degree of their behaviour change is not easy to be estimated. In this study, we try to assess the degree of this behaviour change through a laboratory experiment. The adjustments of experts, with and without a 50-50% combination of system-expert forecast being occurred, are recorded and analysed. We expect that the experts' adjustments will increase in size once they are informed that a subsequent adjustment takes place; one that essentially halves the expert adjustment. In other words, we expect that they will try to mitigate for that further adjustment and retain the ownership of the final forecasts. Additionally, we assess the effect of reporting to experts the value of a 50-50% combination without, however, performing such a subsequent adjustment on the expert forecasts. We expect that the experts on the light of this information will naturally dampen their judgmentally adjusted forecasts towards the statistical ones, emulating this way a 50-50% combination.

2 - Loss-averse decision analysis in overbooking problem

Junlin Chen, Xiaobo Zhao, Deng Gao

The strategy of overbooking capacity is commonly practiced in business that accepts reservations and subsequently runs the risk of cancelations and no-shows. Traditional overbooking models are mainly based on the assumption that decision makers are rationally loss-neutral. This paper seeks the optimal overbooking policies for managers with loss-averse preference towards the loss of compensations for excessive show-up customers. We constructed overbooking models in both single-period and multi-period settings in which the loss-averse preference is described with a kinked piecewise-linear utility function. The analysis demonstrates the optimal policy exhibiting a booking limit structure in both settings. The manager accepts reservation request up to a booking limit if the number of initial reservations is less than that booking limit, and declines reservation requests otherwise. We find that loss-averse managers are cautious and prefer lower booking limits compared to loss-neutral managers. From numerical studies, we investigate the biases between predictions of loss-neutral and loss-averse models. We also investigate how the optimal policy changes with some parameters and the decision maker's degree of loss-aversion.

3 - The influence of individual factors on group decision-making in dynamic environments

Michael Leyer, Jürgen Strohhecker

Decision making in organizations is often characterized by group decisions, for instance, decisions made by the management board. However, individuals being part of such groups have often a predetermined opinion on decision making parameters. In addition they differ in individual capabilities. We observe an environment in which the underlying stock-flow structure of the decision-making problem provides a high dynamic complexity. As group dynamics may occur, it is important to know which individual factors lead to good decision performance. Specifically we analyze what determines the group decision outcome: Is it individual intelligence, individual general economic knowledge, the opinion of the majority or a bad consensus? We put individuals in an experimental situation in which they have to decide as a group on marketing expenses, procurement expenses and dividend payout for five years in a row. Participants are put in the management board of a robot selling company for which they have to maximize the cumulated dividend payout over the five-year period. After deciding on their numbers individually, a group discussion followed by a decision takes place for each of the five years stepwise. The results show how individual abilities influence group decisions. We observe individuals dominating the group decision while others having good ideas are not accepted by the group. The results can be used to explain behavioral dynamics in group decisions in organizations better.

4 - Cognitive regulation and decision conflict in the newsvendor game

Ilkka Leppanen

We argue that decision conflict between the pecuniary motive of profit maximization and the nonpecuniary motive of satisfying customer demand is the driving force behind non-normative behavior in the newsvendor game. We use behavioral newsvendor experiments with a low margin, a high margin and a neutral frame to study this question and demonstrate that decision conflict between pecuniary and nonpecuniary motives affects newsvendor behavior. Using decision time as an indicator of decision conflict we find that "intermediate" situations where demand was not satisfied and the decision was not normative produce more decision conflict and deliberation in the current round than "extreme" situations where either demand was satisfied or/and the decision was normative. We also estimate from the data a parametric utility function model with convex indifference curves and find that decision makers display aversion to underage.

■ WA-28

Wednesday, 8:30-10:00 - 303A

Applications of OR 1

Stream: Applications of OR (contributed)
Contributed session
Chair: Dung-Ying Lin

1 - Analysis of selected economic indices as tools for economic sustainability: Nigeria as a case study

Solomon Nwalozie, Abdulfatai Lawal, Oladipo Rojugbokan

Nigeria economy grew over the years to become largest in Africa in terms of GDP (IMF 2015). But recently recession set in because Nigeria failed to utilize its income earned from oil boom to diversify the economy. In this view, this study used multidimensional analysis to evaluate some selected economic indices of the nation for the pre-oil revenue (1937-1960) and oil revenue (1961-2016) periods. GDP, PCI, and inflation were used as economic indicators, to measure the effect of oil revenue on the nation's economy; Studies have shown that income generated from oil affect the three economic indicators GDP, PCI, and Inflation (Yakubu, 2008 and Ogbonna, 2012). GDP and PCI were found to have positive significant relationship with Oil Revenue (OR). Conversely; Inflation was predicted to posses a negative non-significant relationship with Oil Revenue (Ogbonna, 2012). This study posits that there is a SAVING-GAP period in the Nigeria Economy because for the oil revenue period there is upward movement of the situation graphs for Total Revenue (TR) and Total Expenditure (TE) curves. But negatively sloped Surplus/Deficit (SD) curve indicating how surplus (savings) moved in opposite directions to revenue establishing that there is a SAVINGS-GAP period in which the country failed to reinvest income from oil into other sectors of the economy. The study concludes that oil revenue re-investment to sectors of the economy can end recession and promote sustainable development

2 - Conflict resolution models in the Arctic region
Sergey Shvydun, Fuad Aleskerov

Arctic region has been a matter of intense disputes for the last several decades. The presence of large deposits of natural resources in Arctic such as oil, gas and fish as well as potential economic benefits of shipping routes has already attracted many countries, both Arctic and non-Arctic, thus resulting in potential conflict of interests. Unclear borders and territorial claims made the problem even more complicated. To evaluate the level of conflict of countries and identify high risk areas there is an attempt to estimate the utility of each area in the Arctic region for all countries with respect to main resources - oil, gas, fish and maritime routes. As a result, we present several models of potential conflict resolution based on different preferential allocation of resources among interested countries. Two main approaches are used - each territory is allocated to a single country, and each territory can be allocated to several countries - so called shared allocation. It turns out that shared allocation in general can decrease the total dissatisfaction level of each country. We strongly believe that early forecast of such potential conflict zones and discussions on different scenarios of resource allocation might ease the decision making process in international relations.

3 - The impact of product category, country of origin, involvement and product characteristics on brand attachment
Hellabi Zoubeyda

The study of consumer-brand relationship has become increasingly important for companies that seek to develop long-term customer relationships and secure their position within consumer's mind. The concept of attachment represents the emotional relationship between the consumer and the brand. Moreover, this study aims to empirically investigate the impact of product category, country of origin, involvement and product characteristics on brand attachment. Data are collected from a sample of 400 consumers in Tlemcen, Algeria. Linear regression is used to test the hypotheses. The results indicate that the variables related to the product have a different explanatory power on brand attachment. As such, while involvement toward the product exhibits a strong influence on brand attachment, it remains that the country of origin of the local brand influences negatively brand attachment intensity.

4 - A strategic network model for international container flows
Dung-Ying Lin

Since economic growth and maritime development are closely intertwined, the liner shipping industry is a highly complex system and is extremely sensitive to rapid changes in the environment. To facilitate decision making in response to endogenous and exogenous shocks, this research aims at developing a procedure to analyze the international marine liner shipping network and estimate the possible container flow for liner shipping under different scenarios so that future trends can be forecasted based on the model. Numerical results exhibit the impact of ASEAN increasing freight volume to the area ports, changes in strategic network deployment and strategic alliances and the Panama Canal expansion. By identifying potential impacts on the maritime network, the scheme presented in this paper can help relevant stakeholders avoid risk, capture opportunities and reduce uncertainty when shaping maritime policies so that they can seize opportunities to increase their competitiveness and maintain their advantage in the maritime market.

■ WA-29

Wednesday, 8:30-10:00 - 303B

Operation and planning problems in electric energy systems

Stream: Technical and financial aspects of energy problems
Invited session
Chair: Luis Baringo

1 - Survivable electricity distribution network design using batteries
Ruth Dominguez, Andy Philpott

Improvements in the quality of batteries and a decline in their costs raise the possibility of installing batteries throughout electricity distribution networks to be used in failure events. In this work we tackle the problem of designing survivable electricity distribution networks under line-failure events. A two-stage stochastic-programming problem is proposed which allows to determine the optimal investment decisions in new distribution lines and/or batteries. Particularly, we analyse the cost efficiency of building storage capacity under different cost situations, in comparison with the cost of building new distribution lines considering a radial operation of the network. The proposed model is solved using the Julia programming language under JuMP. In order to solve large-scale problems, we apply a Dantzig-Wolfe decomposition using column generation. Additionally, a realistic-based case study is analysed and numerical results are provided to show the economic and computational outcomes.

2 - Optimal coupling of heat and electricity markets via hierarchical optimization
Lesia Mitridati, S. Jalal Kazempour, Pierre Pinson, Nicoló Mazzi

Increasing the flexibility in the power system is a major challenge to facilitate the penetration of renewable energy sources. This issue can be tackled by improving the coordination between different energy systems, such as heat and electricity, possibly also with gas. For the specific case of heat and electricity, loose interactions already exist due to the participation of Combined Heat and Power (CHP) plants in both markets. Thus, new market mechanisms need to be developed to exploit potential synergies, while respecting the sequential nature of heat and electricity dispatch. This talk will present a novel approach for heat and electricity markets coupling, based on hierarchical (bi-level) optimization. In this model the heat market operator minimizes the expected heat production cost, while endogenously modeling the participation of CHPs in the day-ahead electricity market as lower-level optimization problems. Uncertainties concerning wind power production, electricity demand and rival participants offers in the day-ahead electricity market are modeled using a finite set of scenarios. This bi-level optimization problem is recast as a Mathematical Problem with Equilibrium Constraints (MPEC) by replacing the lower-level problems with their equivalent Karush-Kuhn-Tucker (KKT) conditions. Finally, a Benders decomposition approach will be proposed. This approach allows us to decompose the problem per scenario, resulting in a tractable algorithm for large-scale optimization.

3 - Reserve procurement in power systems with high renewable capacity: How does the time framework matter?
Giorgia Oggioni, Ruth Dominguez, Yves Smeers

In this paper, we investigate reserve procurement in a renewable-dominated power system, focusing both on the moment when reserves are scheduled and on the degree of coordination among Transmission System Operators (TSOs). More precisely, we propose and analyze three stochastic programming models that describe day-ahead energy market, reserve procurement, and real-time balancing market. Taking as reference the US system, the first model (Model 1) represents a stochastic economic dispatch where energy and reserves are co-optimized by an Independent System Operator. The other two models are inspired by the designs of reserve procurement currently applied in Europe, where reserves are committed either before (Model 2) or after (Model 3) the clearing of the day-ahead energy market. In these models, we consider the procurement of both conventional and upward/downward spinning reserves. Numerical results are analyzed through a case study based on the IEEE 24-node RTS, taking into account uncertain renewable power production and demand levels. Our results show that the joint procurement of energy and reserves is the most efficient market design. This happens in Model 1 and, to some extent, in Model 3. Moreover, a coordinated reserve procurement reduces the system operating costs.

4 - Offering strategy for a virtual power plant participating in energy and reserve markets
Luis Baringo, Ana Baringo, José Manuel Arroyo

The production of renewable generating units such as wind- or solar-power units is variable and uncertain. This supposes a problem at the time of participating in different electricity markets since offering decisions must be made before the available production is known. A possible solution is to combine these stochastic units with energy storage facilities or with flexible demands that can adapt their power schedules to the changes in the stochastic production. If generating units, storage facilities, and flexible demands are grouped and operated as a single entity in order to optimize their energy resources, then we have a Virtual Power Plant (VPP). In this talk, we propose a stochastic adaptive robust optimization approach for the offering strategy problem of a VPP that participates in both energy and reserve markets. The VPP faces different sources of uncertainty, namely, market prices, stochastic productions, and reserve requirements. These uncertainties are efficiently modeled using both scenarios (for market prices) and confidence bounds (for stochastic productions and reserve requirements).

■ WA-30

Wednesday, 8:30-10:00 - 304A

Blood system management

Stream: Health care management
Invited session
Chair: John Blake

1 - Modelling the impact of extended shelf life platelets
John Blake

Platelets are blood components that initiate clot formation. Platelets are vital to maintaining hemostasis. Current practice dictates that platelets must be maintained at 22oC. Storing platelets at room temperature, however, increases the potential for bacteria in a contaminated unit to proliferate to clinically significant levels. Risks can be mitigated through processes to ensure donor skin disinfection combined with enhanced bacterial testing. In several European jurisdictions regulatory standards now permit platelets to be stored up to seven days, if an appropriate bacterial testing algorithm is in place. Such algorithms require testing for both anaerobic and aerobic bacteria. Studies suggest that extended shelf life platelets are safe and effective and are believed to have better inventory management characteristics than five-day platelets. Canadian Blood Services plans to implement an enhanced bacterial detection algorithm that will extend shelf life platelets from five to seven days. The enhanced algorithm comes at increased cost, some of which may be recoverable testing through decreased product wastage. This paper describes a process for evaluating the impact of extended shelf life platelets with respect to network level availability and wastage. We describe the design, development, and validation of a simulation model to determine the network inventory impact of extended shelf life platelets.

2 - An age-based lateral-transshipment policy for perishable items
Maryam Dehghani, Babak Abbasi

Lateral transshipment is an efficient policy designed to improve the performance of a supply chain. It allows transferring items between demand points when one demand point might face shortage and another might have extra items. Despite the importance of transshipment for perishable items, few studies consider the issue of perishability. Currently, transshipment in some blood supply chains is based on the age profile of units in hospitals. However, decisions such as the age threshold are made empirically and are fixed for all hospitals. In this paper, we propose a new transshipment policy for perishable items based on the age of the oldest item in the system to improve supply-chain performance. The proposed model has applications for transshipping blood units between hospitals. We develop a heuristic solution using partial differential equations to compute performance measures and cost function. The results demonstrate that our transshipment policy is effective under various circumstances such as lost sale and backordering. We also compare the performance of the suggested transshipment policy to the transshipment policy that is currently practiced in Australian hospitals. The results demonstrate that by setting the optimal threshold, hospitals could transfuse fresher units of blood to the patient in approximately two days while reducing their total inventory cost by approximately 5%.

3 - Coordinated network management for platelets in Canada
Kristyn Reid

The implementation of transshipment policies between hospitals or between hospitals and blood agencies have well documented benefits, such as reduced blood product wastage and improved availability. Yet, in some jurisdictions, such as Canada, regulatory requirements prevent blood agencies from accepting returned products or managing site-to-site transfers. In this study, we look at the potential value of coordinated network management for platelets in the Canadian context. We build a model in which a decision maker can direct the flow of blood products from supply sites to hospitals as well as between hospitals themselves. This is done using a single period assignment model. We then compare this result against a more practical policy of clustering hospitals into hub and spokes. In this policy, platelets are rotated between sites based on strict rules around the age of the platelets. From this comparison, we can calculate the value of perfect network inventory information. We also identify a set of heuristics for developing good hub and spoke clusters.

■ WA-31

Wednesday, 8:30-10:00 - 304B

Additional educational activities for OR

Stream: Initiatives for OR education
Invited session
Chair: Gerhard-Wilhelm Weber
Chair: *Olga Nazarenko*
Chair: *Hans W. Ittmann*

1 - A South African perspective on OR/MS education
Hans W. Ittmann

The education system in South Africa is currently under severe pressure for a whole number of reasons. Education is seen as a right but the majority of students are not properly equipped to attend university. This is especially true of mathematics and science education impacting OR/MS education as well. This paper will present a general context of education in South Africa address issues such as the level of literacy, the low levels of mathematics and science skills, and how this effects university education. The rest of the chapter will then focus on OR/MS education at the South African tertiary institutions. The focus will be on the five main topics covered in the European study of OR/MS education. A qualitative and descriptive view will be presented on what is happening at the South African institutions of higher education as it relates to OR/MS education. The following aspects will be covered namely the enrollment of OR/MS students; addressing 1st year students' failure rates and promoting continuity; the value of OR/MS courses; the teaching practices; and assistance provided by universities to students entering the labor market while highlighting any innovative practices in OR/MS education. Any other issues of relevance will be addressed as well.

2 - A system approach to understand the factors that influence the quality of primary education in developing nations
Gerhard-Wilhelm Weber, Pedamallu Chandra Sekhar, Linet Ozdamar, Hanife Akar, Herman Mawengkang

The system dynamics approach is a holistic way of solving problems in real-time scenarios. This is a powerful methodology and computer simulation modeling technique for framing, analyzing, and discussing complex issues and problems. System dynamics modeling and simulation is often the background of a systemic thinking approach and has become a management and organizational development paradigm. In this paper, we present our experiences and thoughts on developing system thinking models to understand the important factors such as Facilities (includes infrastructure), Local and national political stability, Family migration from rural to urban localities, and socio-economic status of the families on the quality of primary education system in developing nations. This paper provides a high level view on the factors which need to be addressed for providing sustainable education experience to children living in developing nations. In this presentation, we discuss the situations in India, making an application of our method on data from the state of Gujarat, in Turkey and in Indonesia.

3 - Early detection of university students with potential difficulties
Anne-Sophie Hoffait

Using data mining methods, this paper presents a new means of identifying freshmen's profiles likely to face major difficulties to complete their first academic year. We aim at early detection of potential failure using student data available at registration, i.e. school records and environmental factors, with a view to timely and efficient remediation and/or study reorientation. We adapt three data mining methods, namely random forest, logistic regression and artificial neural network algorithms. We design algorithms to increase the accuracy of the prediction when some classes are of major interest. These algorithms are context independent and can be used in different fields. They rely on a dynamic split of the observations into subclasses during the training process, so as to maximize an accuracy criterion. Four classes are so built: high risk of failure, risk of failure, expected success or high probability of success. Real data pertaining to undergraduates at the University of Liège (Belgium), illustrates our methodology. With our approach, we are now able to identify with a high rate of confidence (90%) a subset of 12.2% of students facing a very high risk of failure, almost the quadruple of those identified with a non-dynamic approach. By testing some confidence levels, our approach makes it possible to rank the students by levels of risk and a sensitivity analysis allows us to find out why some students are likely to encounter difficulties.

Wednesday, 10:30-11:30

■ WB-03

Wednesday, 10:30-11:30 - 200AB

Plenary speaker: Martine Labbé

Stream: Plenary sessions
Invited session
Chair: Richard Eglese

1 - Bilevel programming, pricing problems and Stackelberg games
Martine Labbé

A bilevel optimization problem consists in an optimization problem in which some of the constraints specify that a subset of variables must be an optimal solution to another optimization problem. This paradigm is particularly appropriate to model competition between agents, a leader and a follower, acting sequentially. In this talk I will discuss two such problems. In the first one, called the network pricing problem, tolls must be determined on a specified subset of arcs of a multicommodity transportation network. The leader or first level corresponds to the profit maximizing owner of the subset of arcs and the follower to users traveling at minimum cost between nodes of the network. The second problem, called the Stackelberg bimatrix game, involve a party with the capacity of committing to a given action or strategy, referred to as the leader, and a party responding to the leader's action, called the follower. The objective of the game is for the leader to commit to a reward-maximizing strategy anticipating that the follower will best respond.

Thursday, 8:30-10:00

■ HA-01

Thursday, 8:30-10:00 - 307B

Portfolio optimization

Stream: Decision making modeling and risk assessment in the financial sector
Invited session
Chair: *Gerhard-Wilhelm Weber*
Chair: *Derya Dinler*
Chair: *Miyoung Lee*

1 - Reference-dependent expected shortfall: A new risk measure without perceiving tail event
Sumito Onozaki, Junichi Imai

In this research, we give a descriptive framework to risk theory which is the core of mathematical finance. Based on the framework, we propose a reference-dependent expected shortfall (RES) which is descriptive measure of risk. Many studies in psychology claim that people are insensitive to rare events (Tail Events). On the other hand, the tail events are usually emphasized when people discuss normative risk measures. In decision theory, the expected utility theory and the non-expected utility theory are distinguished according to this discrepancy. Many normative risk measures are consistent with a convex utility function. RES, on the other hand, is consistent with a value function in the prospect theory, which has been developed in behavioral economics. It is known that a decision that minimizes the expected shortfall maximizes the expected utility function. In our framework, we showed that there exist the similar relationships between RES and the value function in the prospect theory. RES captures the insensitivity to the tail events by calculating the expected shortfall without the effect of the tail events. Furthermore, we proved some important properties regarding RES.

2 - Risk parity convex optimization algorithm
Evgeny Bauman, Apollon Fragkiskos

Risk Parity is one of the most popular heuristic asset allocation methods today. The idea of the technique is to construct a portfolio in a way such that the risk contribution of different assets within a portfolio sleeve, or the risk contribution of different portfolio sleeves to the portfolio, is the same. The risk measure typically used in the literature to construct a risk parity portfolio is volatility. Although there have been attempts to extend the Risk Parity methodology to other risk measures, such as Downside Risk, Value at Risk or Conditional Value at Risk, algorithms for these cases have not been well developed yet. We present a new Convex Optimization Approach which allows constructing Risk Parity portfolios for any convex homogeneous Risk Measures, such as Volatility, Downside risk and CVaR. We also use Cornish-Fisher VaR as an alternative to historical VaR to create a risk parity portfolio, since it is not a convex measure. A comparative analysis of CVaR, Downside Risk and Volatility Risk Parity portfolios is then carried out. We look at the resulting portfolio performance and risk to identify similarities and differences under a variety of simulated and real data. We then dive into the portfolio composition and evaluate if the asset weights resulted in the desired type of risk parity ex post. Finally, we compare against public risk parity funds to evaluate how useful these measures are from a practical investment standpoint compared to existing offerings.

3 - Risk analysis for project portfolios using a Bayesian network model
Ying Yang, Gang Wang, Dong-Ling Xu

Organizations tend to implement several projects concurrently to maintain flexibility and efficiency. In a multiple-project environment, projects are interdependent and constitute a portfolio linked with the strategic goals of organizations. Due to the interdependencies among projects, new risks emerge additionally to single project risks. It is no longer sufficient to manage solely the risks of single projects in a project portfolio environment. Therefore, this research proposes a risk analysis method specifically for project portfolios using a Bayesian network (BN) model. Firstly, the risk factors in project portfolio management are identified from the organizational perspective, including top management involvement, project manager's competency, formalization of portfolio management and project termination. Then the measurement models of the risk factors are determined by conducting confirmatory factor analysis. The factors' corresponding measurement indicators are designed and confirmed by sample data. Thirdly, a BN model for risk analysis is developed. The initial BN structure is developed based on the measurement indicators and then is optimized by the partial least squares algorithm. Lastly, the BN model is evaluated by conducting a comparative analysis with other advanced methods. Sample data was collected from 169 Chinese companies. Experimental results show that the proposed risk analysis method has high prediction accuracy.

4 - Improved portfolio optimization approach in the sense of out-of-sample performance in the financial field
Miyoung Lee, Jihun Kim, Sekyung Oh

This paper proposes a new portfolio optimization approach that does not rely on the covariance matrix and attains a higher out-of-sample Sharpe ratio than the existing approaches in the financial field. Our approach is free from the problems related to the estimation of the covariance matrix, solves the corner solution problems of the Markowitz model in practice, improves the out-of-sample estimation of portfolio mean, and enhances the performance of portfolio by imposing certain structure on asset returns. Although the shrinkage to market estimator method shows the smallest out-of-sample standard deviation, it cannot perform the best in terms of Sharpe ratio when compared to our approach.

■ HA-02

Thursday, 8:30-10:00 - 308B

Analysis and decision making in queues 1

Stream: CORS SIG on queueing theory
Invited session
Chair: *Gennady Shaikhet*

1 - Diffusion approximations for controlled weakly interacting systems
Eric Friedlander

Analysis of large-scale communication networks (e.g. ad hoc wireless networks, cloud computing systems, server networks etc.) is of great practical interest. The massive size of such networks frequently makes direct analysis intractable. Asymptotic approximations using fluid and diffusion scaling limits provide useful methods for approaching such problems. In this talk, we present a technique for deriving approximate solutions to control problems in these types of systems. Specifically, we consider a rate control problem with a discounted cost criterion for an N-particle, weakly interacting, pure jump, finite state Markov process. An associated diffusion control problem is presented and we show that the value function of the N-particle controlled system converges to the value function of the limit diffusion control problem as N grows to infinity. The diffusion coefficient in the limit model is typically degenerate, however under suitable conditions there is an equivalent formulation in terms of a controlled diffusion with a uniformly non-degenerate diffusion coefficient. Using this equivalence, we show that near optimal continuous feedback controls exist for the diffusion control problem, and then construct asymptotically optimal control policies for the N-particle systems based on such continuous feedback controls. Results for some numerical examples will be presented.

2 - Designing load balancing policies: Lessons from NDS regime
Varun Gupta

We will discuss a fundamental problem in control of queueing systems, load balancing policies for a multi-server system. Our goal is to study the performance of simple heuristics such as Join-Shortest-Queue and Join-Idle-Queue, and the effect of service distribution on the performance of these heuristics. I will try to illustrate why the recently introduced NDS (non-degenerate slowdown) scaling regime is the right regime in which to study these policies – giving non-trivial control policies, as well as insights which are robust to the scale and traffic intensity of the system.

3 - Coverage, coarseness and classification: Determinants of social efficiency in priority queues
Martin Lariviere

We examine differences in how a revenue maximizer and a social planner manage a priority queue. We consider a single server queue with customers that draw their valuations from a continuous distribution and have a per-period waiting cost that is proportional to their realized valuation. The decision maker posts a menu offering a finite number of waiting time-price pairs, which determines coverage (i.e., how many customer in total to serve), coarseness (i.e., how many classes of service to offer), and classification (i.e., how to map customers to priority levels). We show that differences between the decision makers' priority policies are all about classification. Both are content to offer very coarse schemes with just two priority levels, and they will have negligible differences in coverage. However, differences in classification are persistent. A revenue maximizer may - relative to the social planner - have too few or too many high priority customers. Whether the revenue maximizer over- or under-stuffs the high priority class depends on a measure of consumer surplus that is captured by the mean residual life function of the valuation distribution. In addition we show that there is a large class of valuation distributions for which a move from first-in, first-out service to a priority scheme that places those with higher waiting costs at the front of the line reduces consumer surplus.

4 - Dedicated or pooled: Designing queues for large service systems
Junfei Huang

Consider a queueing system with many servers and customer abandonment. Each server has its own queue and customers join the shortest queue upon arrivals. We prove that the probability of delay can be less than one even if the system is overloaded. We also compare the performance measures of this system with the pooled system.

■ HA-03

Thursday, 8:30-10:00 - 200AB

Keynote speaker: Detlof von Winterfeldt

Stream: Keynote sessions
Keynote session
Chair: Natashia Boland

1 - Decision analysis to improve homeland security
Detlof von Winterfeldt

Two years after the 9/11 terrorist attack on the World Trade Center in New York, the US Department of Homeland Security selected and funded the first university based center of excellence, the National Center for Risk and Economic Analysis of Terrorism Events (CREATE). The mission of CREATE is to improve homeland security decisions to make the Nation safer. Researchers at CREATE advanced risk analysis, decision analysis and game theory to assess the risks posed by adaptive adversaries like Al Qaeda and ISIS and to find cost-effective solutions to reduce these risks. This presentation will provide a brief history of the work at CREATE and highlight some of the successes in applying risk and decision analysis to major homeland security problem. Examples include a risk and economic analysis of a dirty bomb attack on the Los Angeles Harbor, deciding whether to put surface to air missile defenses on all wide body commercial airplanes, and protecting infrastructure assets. We will discuss both successes and challenges of using decision and risk analysis to solve homeland security problems and whether these activities made our nation safer.

■ HA-04

Thursday, 8:30-10:00 - 202

Derivative-free approaches to noisy optimization

Stream: Derivative-free optimization
Invited session
Chair: Sandra Santos

1 - Applying a pattern search and implicit filtering algorithm for solving a noisy problem of parameter identification
Sandra Santos, Deise Ferreira, Maria Ehrhardt

In this work, we applied our new globally convergent derivative-free algorithm PSIFA (Pattern Search Implicit Filtering Algorithm), whose range of applicability is linearly constrained noisy minimization problems, for solving the damped harmonic oscillator parameter identification (PID) problem. This PID problem can be formulated as a linearly constrained optimization problem, for which the constraints are related to the characteristics of the damping. Such a formulation comprises a very expensive objective function with inherent noise, the evaluation cost involves the numerical solution of a differential equation, which also possesses intrinsic numerical noise, in addition to the lack of precision from the data. Furthermore, due to the nature of the problem, the derivatives are not available; because of that, PSIFA is a suitable method. Numerical experimentation compares the results with the ones obtained using Pattern Search (R. Lewis and V. Torczon, 2000) and Implicit Filtering (C. T. Kelley, 2011) algorithms.

2 - An approach based on nonmonotone directional direct search to noisy optimization
Ana Luisa Custodio, Samuel Marcos

In industrial applications, mainly in engineering, it is common to be faced with challenging optimization problems where, in particular, the evaluation of the objective function could be contaminated by numerical noise. The presence of this noise prevents the use of derivative based optimization methods. Directional direct search is one of the classes of optimization methods suited for this type of optimization. Nevertheless, when the initialization provided to the optimizer is far from the function minimizer or when in presence of noise with quite irregular oscillations (like is the case of Gaussian noise), modifications are required in order to make it more robust/efficient. We propose to use nonmonotone approaches, where the value of the objective function is not required to improve between consecutive iterations, but along an historic of iterations. This procedure allows to escape from spurious minima, resulting from the presence of noise. In this talk we will detail the nonmonotonous variants of directional direct search considered, present the corresponding theoretical results related to convergence and report their numerical performance.

3 - On the construction of quadratic models for derivative-free trust-region algorithms
Adriano Verdério, Elizabeth Wegner Karas, Lucas Garcia Pedroso, Katya Scheinberg

We consider derivative-free trust-region algorithms based on sampling approaches for convex constrained problems and discuss two conditions on the quadratic models for ensuring their global convergence. The first condition requires the poisedness of the sample sets, as usual in this context, while the other one is related to the error between the model and the objective function at the sample points. Although the second condition trivially holds if the model is constructed by polynomial interpolation, since in this case the model coincides with the objective function at the sample set, we show that it also holds for models constructed by support vector regression. These two conditions imply that the error between the gradient of the trust-region model and the objective function is of the order of the radius that controls the diameter of the sample set. This allows proving the global convergence of a trust-region algorithm that uses two radii, the sample set radius and the trust-region radius. Numerical experiments are presented for minimizing functions with and without noise.

■ HA-05

Thursday, 8:30-10:00 - 203

New risk management

Stream: Financial and commodities modeling
Invited session
Chair: *Rita D'Ecclesia*
Chair: *Gerhard-Wilhelm Weber*
Chair: *Yuriy Kaniovskyi*

1 - Too-big-to-fail: The value of implicit government guarantee
Georges Tsafack

Following the 2008 financial crisis and the government bailout of troubled companies, Too-Big-to-Fail became a standard expression to name a free protection of Wall Street by tax-payers' money. What should have been the fair cost of this protection? We offer an appropriate way to estimate the value of the implicit government guarantee by combining the contingent claim pricing with the likelihood of the government intervention. We find in our sample that the cost of this implicit protection can go beyond tens of billions of dollar with an average of about $13 million per company, per year, and it rises to about $24 million if the government is assumed to intervene with certainty. We then investigate the relationship between the implicit government guarantee and the funding costs of small and large banks. We find that the funding costs for both small and large banks are related to the value of the implicit government guarantee. Moreover, we show that the spread of the funding costs of small banks over large banks is strongly associated with the value of the implicit government guarantee, especially after the crisis.

2 - A study of uncertainty in an operational process model to determine risks
Oroselfia Sanchez, Idalia Flores

Risks identification has changed its definition over the years, due to the requirements and challenges of today. This first step of risk management nowadays seeks the clear description of risk including the causes and effects that could distinguish each risk. The techniques most commonly used are soft methods, based on the perception and opinions of expert groups on projects, processes or specific areas under analysis. This has gradually been changed by the incorporation of hard and quantitative techniques and even the use of analogies with physics theories. The new challenges in risks framework include incorporation of complexity, reduction of ambiguity and addition of uncertainty. That is why the use of models allows to analyze systems that present risks using hard methods and techniques, being simulation one of the most employed. The purpose of this work is to analyze a system including uncertainty as a part of modeling. The uncertainty can be generated on the basis of estimations made for the model, due to the lack of information that the system may present. In addition, possible interrelationships between parts of the same system increases diversity. In particular, we use entropy in order to quantify such diversity. Finally, the methods developed are then applied to determine the risks in an oil-well cementing process.

3 - Dependent credit-rating migrations: A heuristics for estimating unknown parameters
Yuriy Kaniovskyi, Georg Pflug, Yuriy Kaniovskyi

Modeling dependent credit-rating migrations, the number of unknowns of proportional to exp(MS), if debtors are classified into M non-default credit-classes and S industries. For a typical choice of M and S, this is a hard task for a desktop computer and a standard solver. A heuristics is suggested such that: initially a simplified problem with approximately exp(M) parameters is solved, thereafter, the number of unknowns does not exceed a couple of hundreds. For M=2 and S=6, two models of dependent credit-rating migrations and the respective maximum likelihood estimators are tested on S&P's data. Using MATLAB optimization software, exact solutions and their heuristic approximations are evaluated and compared.

■ HA-06

Thursday, 8:30-10:00 - 204A

Understanding the practice of problem structuring methods

Stream: Problem structuring interventions
Invited session
Chair: *Mike Yearworth*

1 - Developing a study of naturally occurring problem structuring
Eleanor Reynolds

This talk is concerned with naturally occurring problem structuring. That is, problem structuring activity in which the actors are not following, perhaps not even aware of, the academically developed approaches that we call problem structuring methods (PSMs). I will explain why I believe it is relevant to study naturally occurring problem structuring before describing two options for identifying when a group of actors are doing the activity of problem structuring. My study is based at a UK utilities company where I have a working knowledge of the culture and types of issues arising. Drawing upon the relatively recent and dispersed literature on living laboratories, I will present the development of my study design and share early research findings.

2 - Strategic city planning: The compatibility of PSMs with(in) practice
Ine Steenmans

The suitability of PSMs for resolving the messy problems targeted by strategic planning is generally accepted. In practice, however, there exists an 'adaption gap' where soft OR methods remain less frequently employed than might be expected. It is argued that at the level of practice, more systematic adaptation of the formats of PSM interventions to meet the unique requirements of varying contexts of their application would contribute to closing this 'adoption gap'. As Ormerod (2014) argues, accounts of PSM use typically omit details of the messy and 'mangled' realities of practice, consequently limiting the extent by which insights about the impacts of adaptations and innovations in PSM application are shared between practitioners. This research aims to contribute to this knowledge gap by exploring how different contextual pressures influence the *compatibility* of PSMs with different working practices and cultures. It draws analyses of 4 strategic city planning projects in which PSM interventions were made. In order to demonstrably link the consideration of PSM compatibility to outcomes of practical adaptations to their formats, a causal complex systems model of PSM use collaborative planning practice is presented.

The work concludes by arguing that critical factors shaping the compatibility and attractiveness of PSM use in practice are considerations of time costs, reputational impacts, and support of professional learning and development processes.

3 - Choosing and combining problem structuring methods in practice
Jane Christie

When OR practitioners address complex strategic issues with organizations, they often combine problem structuring methods (PSMs) such as soft systems methodology with other methods. It has been argued that this mixing of methods, or multi-methodology, is needed to address dynamic, multi-dimensional and uncertain problem situations across different intervention phases, and to enhance and corroborate findings. However, empirical evidence of how analysts make method decisions and of the effectiveness of multi-methodological practice across methods and interventions appears to be limited. In this presentation I shall review preliminary results from current research into how PSMs and other methods are and could be chosen and combined by practitioners in order to benefit from multi-methodology. First, I shall review results from a literature review exploring its prevalence, forms and theoretical frameworks. Second, I shall describe an ongoing empirical exploration of the use and effectiveness of multi-methodology across multiple practitioners and decision support interventions using questionnaires, semi-structured interviews, workshops and secondary data review. I shall conclude by using theoretical guidance and practical insights to propose future directions for research into the practice of PSMs.

4 - Developing a set of constitutive rules for using the viable system model in real world applications
Mike Yearworth, Angela Espinosa, David Lowe

The Viable System Model (VSM) is the theoretical framework developed by Stafford Beer to describe the patterns of viability and adaptation in organizations and businesses. It has been successfully applied to guide organisational interventions in organisational settings as diverse as large multi-national corporations, complex government projects, disaster response, green businesses design, combatting transnational organised crime and supply chains. In spite of these numerous successes, the cognitive accessibility of VSM as a modelling approach has repeatedly been highlighted as a barrier to application. We propose a set of constitutive rules to guide the application of VSM and so make a contribution to overcome the difficulties experienced in real world settings. These rules are developed first from Beer's theoretical basis and then refined from the experiential basis drawn a number of VSM practitioners. Specifically, we describe three recent VSM interventions where the original theory and tools have been adapted to suit the needs of their particular operational contexts as cases of non-codified use of problem structuring methods. These descriptions are intended to encourage wider use of the VSM.

■ HA-07

Thursday, 8:30-10:00 - 204B

Routing with time window or duration constraints

Stream: Vehicle routing
Invited session
Chair: Maaike Hoogeboom

1 - Efficient move evaluations for time-dependent vehicle routing problems with route duration constraints
Thomas Visser, Remy Spliet

We consider the Vehicle Routing Problem with Time Windows, time-dependent travel times and in which route duration is constrained or minimized. This problem arises in many real world transportation applications, for instance when modeling road traffic congestion and driver shifts with maximum allowed working time. To obtain high quality solutions for instances of 1000+ requests, (meta-) heuristics are needed, which typically rely on some form of Neighborhood Search. In such algorithms, it is crucial to quickly check feasibility and exact objective change of local improvement moves. Although constant time checks based on preprocessing are known for both the time-dependent VRPTW, and the VRPTW with duration constraints, the combination of the two is significantly harder, leading to quadratic time complexity in the number of requests. We show how preprocessing can be used to decrease the move evaluation complexity from quadratic to linear time. Furthermore, we introduce a new data structure that reduces computation times further by maintaining linear time move evaluation complexity even when the neighborhood is searched in non-lexicographic order. We support our complexity results by presenting numerical results of various benchmark instances.

2 - Vehicle routing problem for perishable items with time windows
Ji-Su Kim, Li Liu, Chi-Guhn Lee

We consider a vehicle routing problem for perishable items such as fresh food when customers have delivery time windows. The objective is to minimize the sum of variable operation costs and cooling costs while the items delivered are to meet the quality requirement set by customers. The problem is an extension of the Vehicle Routing Problem with Time Window (VRPTW), which deals with optimal routing of a fleet of vehicles between a depot and a number of customers requiring delivery during specific time windows. We assume that the quality is decreasing in time and the deterioration of the quality begins with the departure at the depot. We adopt the exponential degradation model, which is commonly used in the food quality literature, and formulate the resulting routing problem as a mixed integer-programming model. We propose a branch and bound algorithm to solve the problem with bounds found using the Lagrangian relaxation. Numerical studies are presented to show the efficiency of the algorithm as well as to reveal how the quality constraints impact on the routing decisions.

3 - The traveling salesman problem with time windows in postal services
Alexis Bretin, Guy Desaulniers, Louis-Martin Rousseau

Parcel delivery is becoming more and more important in postal services. In a predefined postman territory, one must visit every customer but only some of them (about 10%) have a time window, typically, the commercial customers. Most of the known algorithms for solving this traveling salesman problem with time windows (TSPTW) strongly rely on the time windows to significantly reduce the solution space. In this talk we propose some clustering and disaggregation procedures to obtain a reduced-sized problem and lower its combinatorial dimension. Given that minimizing the traveled distance (the mostly common objective function studied for the TSPTW) may lead to undesirable waiting time, we also consider a multi-objective version of this problem. To solve it, we developed two approaches: one relies on constraint programming and the other on a mixed integer program based on time buckets. Comparative computational results obtained on real-life instances will be reported.

4 - Vehicle routing problem with arrival time diversification
Maaike Hoogeboom, Wout Dullaert

We propose a novel method to generate sufficiently unpredictable routes by varying the arrival time at each customer, while minimizing transportation costs. By removing the previous arrival time slots at each customer from the solution space, the problem becomes a Vehicle Routing Problem with Multiple Time Windows (VRPMTW) in which every customer has a set of time windows in which it is still available for service. Because of the reformulation into a VRPMTW with a rolling horizon, our approach is easier, more efficient and more powerful than existing methods. Since waiting times are not allowed a new method is proposed to check if a route is time window feasible. To allow time window violations during the local search, four different penalty methods are proposed and compared in terms of solution quality and computational time. The routing problem is solved using an iterated granular tabu search which finds new best-known solutions for all benchmark instances from the literature. The proposed method reduces average distance with 28% and computational time with 91%. A case study is performed on data from a Cash in Transit company that transfers valuable goods to banks and ATMs. For security and legal regulations they have to use varying routes and computational experiments show the savings potential of the proposed solution approach and quantify the trade-off between arrival time diversification and transportation costs.

■ HA-08

Thursday, 8:30-10:00 - 205A

Data science and analytics 2

Stream: Data science and analytics (contributed)
Contributed session
Chair: Wonsang Lee

1 - Dynamic management for software errors and product recall
John Wilson

We formulate a model of incompatibility errors which is especially applicable to today's world of software on the internet and on smartphones. New errors of incompatibility are introduced as systems age. New users also arrive over time. Allowing new users and errors to enter dynamically complicates estimation and requires more than standard static models. Often a decision have to be made on when to upgrade or recall a system. Data concerning errors arrives dynamically. We provide a procedure for finding maximum likelihood estimators of key parameters where the number of possible error types and users changes dynamically. The procedure is iterative and is easily updated as new information arrives. This makes it particularly appealing in an age of big date since key managerial quantities are dynamically updated as data becomes available. The procedure allows for an easy control chart approach to monitoring as an aid to product recall decisions.

2 - Vulnerability assessment for populated areas: Case of study Bucaramanga (Colombia)
Daniel Orlando Martinez Quezada, Henry Lamos, Gustavo Chio Cho

According to the National Seismological Network of Colombia, the city of Bucaramanga is located in a high seismic activity area; factors such as accelerated urbanization, low prevention in terms of meeting the minimum requirements to ensure an earthquake resistant construction, it makes possible losses and number of affected considerable high in an earthquake scenario. For a proper Risk Management, knowing the risk is important; moreover, knowing the vulnerable elements within a system is also important. Different approaches have been developed allowing the assessment of vulnerability of important elements in the disaster risk management process, analytical approaches derived from the physical analysis of the elements involved and the use of expert criteria have been used, the last one is also known as Expert Systems (ES), which through machine learning models allows to generalize the knowledge of an expert in a specific task. Therefore, this work proposes the development of an Expert System to identify vulnerable zones for a seismic event based on structural and geological features in the city of Bucaramanga, which will be an input for the development of a Decision Support System (DSS) for supporting pre-disaster activities in the city of Bucaramanga (Colombia); machine learning models such as: support vector machines, artificial neural networks and decision trees will be evaluated in order to perform a comparative analysis and identify the model with the best fit.

3 - Measuring and profiling e-government stages of nations: An application of unsupervised learning technique
Nigussie Mengesha, Dawit Demissie, Anteneh Ayanso

Governments across the globe have invested huge resources on eGovernment to redefine the interaction between administration and citizens, and create an electronic, minimal, more transparent, agile and accountable state. eGovernment has the potential to improve the quality and efficiency of processes, and reduce administrative burden on citizens by making their interactions with public administrations faster and efficient, more convenient and transparent, and less costly. Led by international players, developing countries have committed resources to develop infrastructures, policies and procedures to create an environment conducive for eGovernment. Progress has been made in delivering information and public services electronically to citizens using governmental websites, however different the progress has been. A number of models have been developed to evaluate the progress that each government has made and assign an eGovernment index to it. These models, however, did not go beyond ranking and indexing countries. This paper fills this gap by profiling each African country's electronic service offerings, classifying them according to their common characteristics, and exploring the factors that have contributed towards the differences and similarities. The paper presents the results of the analysis of 582 eGovernment service websites of 53 African countries using unsupervised machine learning technique, and shows its implications towards the study and practice of eGovernment.

4 - Analyzing topic transitions of innovations in emerging areas
Wonsang Lee

Technological innovation is essential in order to survive intense competition and market saturation. Particularly, it can be effective to pursue the technological innovation in emerging areas. The emerging areas have various topics, and such topics experience the evolution, such as the co-existence, competition, or extinction. Therefore, understanding the topic transitions of emerging areas can contribute to further pursuing the technological innovation. In terms of user-centered innovation, this paper focuses on the crowd-funding platform, where the innovative ideas and technologies can be promptly generated and commercialized. In this paper, I identify the emerging areas from the crowd-funding platform. Then, the topic modeling technique is applied for extracting the hot topics from those emerging areas. The structure of topic transition is examined to provide a better understanding of topic dynamics of emerging areas and their exploitation. A Markov chain is applied to the analysis of topic transition, and I further attempt to analyze the changes of topic dynamics over years. The article is one of the first studies to discover the structure of topic transitions with use of crowd funding platform. The empirical evidences of this paper encourage further studies into the systematic investigation of topics from crowd funded innovations. Those findings also offer practical implications for management concerning crowd funding.

■ HA-09

Thursday, 8:30-10:00 - 205B

Decomposition methods in logistics and transportation

Stream: Discrete optimization in logistics and transportation
Invited session
Chair: Ivan Contreras

1 - A Benders based exact algorithm for the uncapacitated multicommodity network design problem
Carlos Zetina, Ivan Contreras, Jean-François Cordeau

In this study, we present a novel exact algorithm for the uncapacitated multicommodity network design problem. Our algorithm combines the use of a modified Benders reformulation of the model, bound strengthening via Lift-and-Project cuts and heuristics to obtain primal bounds.

We analyze the performance of the algorithm on benchmark instances and compare them with current solution methods.

2 - Combinatorial bounds and cuts for the CDAP
Carlos Luna-Mota, Ivan Contreras, Jean-François Cordeau

The Cross Docking Assignment Problem (CDAP) is an NP-Hard combinatorial optimization problem that arises naturally in the context of the design of efficient distribution networks. The CDAP is computationally challenging due to the quadratic component of the objective function that links what will otherwise be two independent Generalized Assignment Problems (GAP). In this work we study new combinatorial bounds and several families of valid cuts for the CDAP. We use these elements to propose new exact algorithms for the CDAP.

3 - An exact algorithm for multi-level uncapacitated facility location problems
Camilo Ortiz Astorquiza, Ivan Contreras, Gilbert Laporte

We study a general class of multi-level uncapacitated p-location problems in which the selection of links between levels of facilities is part of the decision process. An exact algorithm based on a Benders reformulation is proposed to solve large-scale instances of the general problem and some well-known particular cases. We exploit the network flow structure of the reformulation to efficiently generate Pareto-optimal cuts. Extensive computational experiments are performed to assess the performance of several different variants of the Benders algorithm. Results obtained on benchmark instances with up to 3,000 customers, 250 potential facilities and four levels confirm its efficiency.

4 - A comparison of formulations and relaxations for cross-dock door assignment problems
Ivan Contreras, Wael Nassief, Brigitte Jaumard

This talk deals with static cross-dock door assignment problems in which the assignments of incoming trucks to strip doors, and outgoing trucks to stack doors are determined, with the objective of minimizing the total handling cost. We present new mixed integer programming formulations which are theoretically and computationally compared with existing ones. We present the results of a series of computational experiments to evaluate the performance of the formulations on a set of benchmark instances.

■ HA-10

Thursday, 8:30-10:00 - 205C

Recent advances in location analysis

Stream: Location
Invited session
Chair: Francisco Saldanha-da-Gama

1 - A Benders decomposition approach for location of charging stations in an electric car sharing system with demand uncertainty
Hatice Calik, Bernard Fortz

Car sharing systems have a high potential of decreasing the traffic congestion and parking problems in urban areas through shared use of vehicles. Usage of electric cars plays an important role in increasing attractiveness of these systems together with provision of accessibility and more flexibility. We focus on a one-way station-based car sharing system with a fleet of identical electric cars. The system under consideration provides flexibility in the sense that the users are allowed to leave the cars to stations different then their pick-up point and no pre-booking is enforced, which leads to uncertainty in demand. We approach the system from a strategic point of view and aim to decide on the location of stations and the initial number of cars available at each station in a way to maximize the expected profit. The objective function takes into account the expected revenue obtained from the user requests served and the fixed costs of opening stations and purchasing cars. We introduce multiple demand scenarios to represent the demand uncertainty and generate these scenarios based on real data to use in our experiments. We develop a Benders decomposition algorithm based on a mixed integer stochastic programming formulation that we proposed for solving this problem. We conduct a comprehensive experimental study to compare the performance of our methods with and without several enhancement components.

2 - A generalized model for plant location
Mercedes Pelegrin, Alfredo Marín

In the Simple Plant Location Problem (SPLP) a set of clients and plants are given. Considering that each plant has an opening cost and each pair plant-client has an assigning cost, two decisions are to be made: which plants will be open and which client will be served by which plant. The SPLP can be formulated as a set-packing problem. We explore an original variant of the SPLP. The problem we tackle differs from the classic version of the SPLP in the fact that possible incompatibilities between clients are considered. Two clients are said to be incompatible if they cannot be served by the same plant. Incompatibilities add a new family of set-packing constraints to the classic set-packing formulation of the SPLP. We study the corresponding polyhedron, which is a thighter version of the polyhedron of the classic formulation of the problem. The model we tackle can be also seen as a generalization of other previously studied variants of the SPLP. Different facets originated by cliques and holes in the conflict graph of the set-packing formulation are described. Unlike clique inequalities, those corresponding with holes need to be lifted in order to become facets. We give a procedure to lift inequalities of this type. The proposed techniques are based on sequential lifting and on an original lifting theorem. A preliminar computational study, which incorporates some separation algorithms in the context of a branch-and-bound procedure, is presented.

3 - Formulations for the discrete ordered median problem with novel features
Diego Ponce, Alfredo Marín, Justo Puerto

The Discrete Ordered Median Problem, DOMP, is a modeling tool that provides flexible representations of a large variety of problems, which include most of the classical discrete location problems considered in the literature. It consists in minimizing a globalizing function that assigns weights depending not of the costs induced by the facilities themselves but to their position in the relative vector of ordered costs. When the ordered weighted vector satisfies the monotonic, i.e. its coefficients are non-decreasing, we can apply specific formulations which have a better performance. Based on latter formulations for the Monotone Ordered Median Problem, we present in this work some novel formulations for the DOMP. In particular, we foreground one formulation which models the problem using continuous variables but for the location variables.

4 - A new class of continuous facility location problems
Jack Brimberg, Anita Schöbel

In classical facility location problems such as the multi-source Weber problem (also known as the continuous location-allocation problem) or the continuous p-centre problem, it is assumed that customers get full service from their closest facilities. We generalize this idea by allowing demands to be distributed to the k facilities that are closest (or furthest) to each customer. Some preliminary results for the standard minsum and minmax criteria are obtained for a range of distribution rules considered. Potential applications include the field of "robust" location.

■ HA-11

Thursday, 8:30-10:00 - 206A

Decomposition methods

Stream: Telecommunications and network optimization
Invited session
Chair: Dimitri Papadimitriou

1 - Optimal aggregated ConvergeCast scheduling
Mahesh Bakshi, Brigitte Jaumard, Lata Narayanan

We consider the scheduling problem for Aggregated ConvergeCast in wireless sensor networks with the physical model for interference. Previous work on the problem has provided either heuristics without performance guarantees, or approximation algorithms which do not perform well in practice. We propose here a first mathematical model that outputs an optimal Aggregated ConvergeCast schedule. Since the resulting Integer Linear Program (ILP) model is computationally hard to solve, we use large scale optimization techniques, namely a Dantzig-Wolfe decomposition algorithm, to solve it. We per- formed extensive simulations on networks with upto 70 sensors, and compared our results with one of the best heuristics in the literature [1]. Our results show that our ϵ-optimal schedule is significantly better than the previous best schedule, i.e., it s6 produces TDMA frames that are up to 75% shorter.

2 - A dual decomposition framework for the two-stage stochastic Steiner tree problem
Markus Sinnl, Markus Leitner, Ivana Ljubic, Martin Luipersbeck

In this talk, we consider the two-stage stochastic Steiner tree problem (SSTP). In the SSTP, we are given a graph G=(V,E) with first-stage cost c on the edges. The set of terminals (subset of V, which needs to be connected) is only revealed in the second stage, in which also additional edges can be purchased at a higher cost. The second stage is modelled by a finite set of scenarios S with probability p_s, terminal set T_s, and second-stage cost q_s on the edges for each scenario s in S. A feasible solution of the SSTP consists of a set of edges E_0 purchased at the first stage, and edge sets E_s, for each scenario s in S, of edges purchased in the second stage. The union of E_0 and E_s must connect T_s for each s in S. The objective function is defined as the cost of E_0 and the expected cost of the second stage solution. The goal is to find a feasible solution of minimum cost.

We present a new formulation for the SSTP and develop an exact solution framework for the SSTP based on dual decomposition and branch-and-bound. We also investigate the use of a dual ascent algorithm to solve the subproblems occurring within the dual decomposition. Further ingredients of the framework are reduction tests and primal heuristics. Computational experiments on a large set of instances from literature, as well as newly introduced large-scale instances reveal that our framework is competitive with state-of-the-art exact approaches for the SSTP and even outperforms them in many cases.

3 - Logic-based Benders decomposition for the capacity- and load-constrained task allocation problem
Dimitri Papadimitriou

The problem at hand extends the fixed-charge multiple knapsack problem (FCMKP) with load constraints. Each capacity-constrained knapsack (e.g., computing center) comprises a set of modules (e.g., processors) on which to load the task(s) received from a scheduler. Multiple tasks can be assigned to a given module as long as their sum doesn't exceed the maximum load that the assigned module can sustain. The goal is to select the set of knapsacks, determine the number of modules required at each knapsack, and find the assignment of tasks to knapsacks (without exceeding their capacity) and modules (without exceeding their load) that maximizes the total profit. This problem combines different types of decision variables: decisions on which knapsacks to select that have global implications in terms of profit and local decisions concerning the allocation of modules for the loading of individual tasks. As the decisions at each knapsack are decorrelated, they form independent bin-packing problems. These reasons suggest exploiting the hierarchical and modular structure of the problem for faster resolution on large instances. For this purpose, we partition the formulation into a FCMKP master problem and a set of bin-packing subproblems following the logic-based Benders decomposition (LBBD) method. Compared to other mixed-integer programming methods, this procedure is more efficient both in time and space since significantly smaller subproblems can be solved iteratively.

■ HA-12

Thursday, 8:30-10:00 - 206B

Multiple criteria decision making and optimization 2

Stream: Multiple criteria decision making and optimization (contributed)
Contributed session
Chair: Majed Al-Shawa

1 - Purchasing professional services: Differences in managers' choice of decision criteria
Mahmut Sonmez

Selecting the best and "right" professional service provider is a critical endeavor for any organization. An online survey of global companies was conducted. The findings of this survey on the importance of decision criteria and differences in managers' preferences among decision criteria will be presented.

2 - The logarithmic least squares optimality of the geometric mean of weight vectors calculated from all spanning trees for (in)complete pairwise comparison matrices
Sándor Bozóki, Vitaliy Tsyganok

Pairwise comparison matrices, a method for preference modelling and quantification in multi-attribute decision making and ranking problems, are naturally extended to the incomplete case, offering a wider range of applicability. The weighting problem is to find a weight vector that reflects the decision maker's preferences as well as possible. The logarithmic least squares problem has a unique and simply computable solution. The spanning tree approach does not assume any metric in advance, instead it goes through all minimal sufficient subsets (spanning trees) of the set of pairwise comparisons, then the weight vectors are aggregated. It is shown that the geometric mean of weight vectors, calculated from all spanning tress, is the optimal solution of the well known logarithmic least squares problem, not only for complete, as it was recently proved by Lundy, Siraj and Greco, but for incomplete pairwise comparison matrices as well.

3 - Multi-attribute replacement policy in a cumulative damage model
Shey-Huei Sheu

The purpose of this paper is to investigate an optimal preventive replacement policy based on multi-attributes in a two-unit system. The system is subject to two types of shocks (I and II) and the probabilities of these two shock types are age-dependent. Each type I shock causes a minor failure of unit A and yields a random amount of additive damage to unit B and type II shock causes the system to fail completely. Unit B may also fail with a probability and be rectified by a minimal repair. In this study, we consider a replacement policy based on system age, nature of failure, number of type I shocks, and the cumulative damage to unit B. To minimize the expected cost per unit time, the optimal policy is derived analytically and computed numerically. The proposed model, extending many existing models, provides a general framework for analyzing maintenance polices.

4 - Is it worth fighting a patent troll? Using the constrained rationality framework to model and analyze the showdown between RIM and NTP, as an example
Majed Al-Shawa

In late 2001, Research in Motion Ltd (RIM), the game-changer famous for the BlackBerry device, found itself defending itself in what initially looked like a small normal patent infringement lawsuit against NTP Inc., a patent holding company with no real products. Four and a half years later, RIM found itself mysteriously embroiled in a battle for its own survival. The conflict between RIM and NTP holds many features of a classical strategic business conflict that real product innovators found themselves facing: a patent troll holding patents on paper with no real products asking them to pay licensing fees or stop production. Do they settle and pay? If yes, when and why? If no, why? And for how long they should keep fighting the patent troll? We use the Constrained Rationality framework, a formal value-driven enterprise knowledge management for strategic decision and conflict analysis framework with robust multi-agent decision support methodological approach to: model the RIM vs. NTP strategic conflict; analyze the players options and strategies including the possible cooperation between RIM and NTP to settle, and the possible formation of coalitions between NTP and RIM's competitors; and then elicit the most stable equilibrium end states of this conflict, and similar ones. We, finally, compare the analysis produced by the framework's contextual cooperative game models and coalition analysis with how the conflict actually ended; and conclude by discussing our findings.

■ HA-13

Thursday, 8:30-10:00 - 207

Conic and bilinear relaxations

Stream: Copositive and conic optimization
Invited session
Chair: *Immanuel Bomze*

1 - Linearized robust counterparts of two-stage robust optimization problem
Amir Ardestani-Jaafari, Erick Delage

We study two-stage robust optimization problem wherein some decisions can be made when the actual data is revealed. Since this problem is computationally intractable we propose a conservative tractable approximation scheme for this problem based on linearizing the bilinear terms that appears due to the recourse problem. We relate this new scheme to methods that are based on exploiting affine decision rules. Furthermore, we show that our proposed method can be exploited to provide exact solutions in a family of robust multi-item newsvendor problem. Using a robust operating room allocation problem, we also show how our proposed method can be used to derive conservative approximations that are tighter than existing tractable methods.

2 - A fresh CP look at mixed-binary QPs: New formulations and relaxations
Jianqiang Cheng, Immanuel Bomze, Peter Dickinson, Abdel Lisser

Triggered by Burer's seminal characterization from 2009, many copositive (CP) reformulations of mixed-binary QPs have been discussed by now. Most of them can be used as proper relaxations, if the intractable co(mpletely)positive cones are replaced by tractable approximations. While the widely used approximation hierarchies have the disadvantage to use positive-semidefinite (psd) matrices of orders which rapidly increase with the level of approximation, alternatives focus on the problem of keeping psd matrix orders small, with the aim to avoid memory problems in the interior point algorithms. This work continues this approach, proposing new reformulations and relaxations. Moreover, we provide a thorough comparison of the respective duals and establish a monotonicity relation among their duality gaps. We also identify sufficient conditions for strong duality/zero duality gap in some of these formulations and generalize some of our observations to general conic problems.

3 - Semi-Lagrangian relaxations of CDT problems - a copositive view
Immanuel Bomze, Vaithilingam Jeyakumar, Guoyin Li

We present exact copositive relaxation and global optimality conditions for an extended trust-region problem under suitable conditions by way of studying its semi-Lagrangian duality. We then establish novel conditions under which exactness of the semi-Lagrangian relaxation, or of the usual Lagrangian relaxation, holds for an extended CDT (two-ball trust-region) problem.

■ HA-14

Thursday, 8:30-10:00 - 305

Metaheuristics: VNS, TS, SA

Stream: Metaheuristics - Matheuristics
Invited session
Chair: *Abraham Duarte*
Chair: *Nicolle Clements*

1 - An effective hybridisation of adaptive variable neighbourhood search and large neighbourhood search for the cumulative capacitated VRP
Said Salhi, Jeeu Fong Sze, Niaz Wassan

The cumulative capacitated vehicle routing problem (CCVRP) is a relatively new variant of the classical capacitated vehicle routing problem in which the objective is to minimize the total arrival times at customers, instead of the total route distance. The CCVRP has useful applications such as in the context of supplying humanitarian aid after a natural disaster where the delivery time is important to minimize life losses or sufferings. In this paper, an adaptive variable neighbourhood search (AVNS) algorithm that incorporates large neighbourhood search (LNS) as a diversification strategy is proposed and applied to the cumulative capacitated vehicle routing problem (CVRP). The AVNS consists of two stages: a learning phase and a multi-level VNS with guided local search. The adaptive aspect is integrated in the local search where a set of highly successful local searches is selected based on the intelligent selection mechanism. To make the algorithm more competitive in terms of the computing time, a simple and flexible data structure and a neighbourhood reduction scheme are embedded. When tested on the benchmark data sets from the literature, the proposed AVNS produced very promising results, with several new results reported.

2 - Behavior of neighborhood operators in a variable neighborhood search
Sandra Huber, Martin Josef Geiger

The behavior of standard and problem specific neighborhood operators is addressed in a Variable Neighborhood Search (VNS) for the Swap-Body Vehicle Routing Problem (SB-VRP). We propose an experimental setting that supports the determination of a promising sequence. Experiments are conducted on benchmark instances and the numerical results show that the order of operators is indeed important. When compared to existing solution approaches we can achieve competitive results. Additionally, we apply our algorithm with the identified sequence to previously untested instances, which can be downloaded on the following homepage: http://www.vrp-rep.org/datasets.html. Without any further modifications of the algorithm several new best known solutions can be obtained.

3 - Adaptive tabu search with strategic oscillation for the bipartite boolean quadratic programming problem with partitioned variables

Yang Wang, Qinghua Wu, Abraham Punnen, Fred Glover

The bipartite boolean quadratic programming problem with partitioned variables (BQP-PV) is an NP-hard combinatorial optimization problem and accommodates a number of real-life applications. We propose an adaptive tabu search with strategic oscillation (ATS-SO) approach for BQP-PV, which employs a multi-pass search framework where each pass consists of an initial constructive phase, an adaptive tabu search phase and a frequency-driven strategic oscillation phase. In particular, the adaptive tabu search phase combines different move operators to collectively conduct neighborhood exploration and an adaptive tabu tenure management mechanism that obviates the task of determining a proper tabu tenure. The frequency-driven strategic oscillation phase diversifies the search when the search reaches a critical solution, drawing on a destructive procedure to unassign some variables by reference to frequency memory and a constructive procedure to re-assign these variables utilizing both frequency memory and problem specific knowledge. Computational experiments on five classes of problem instances indicate that the proposed ATS-SO algorithm is able to find improved solutions for 13 instances and match the best known solutions for all remaining instances, whereas no previous method has succeeded in finding the previous best solutions for all instances. Statistical tests indicate that ATS-SO significantly outperforms the state-of-the-art algorithms in the literature.

4 - Heuristic approach to multidimensional assignment of grid points for effective vegetation monitoring and land use in east Africa

Nicolle Clements, Virginia Miori

Trend changes in vegetation give valuable information toward effective land use and development. In this research, vegetation trends are studied in the East African region based on the Normalized Difference Vegetation Index (NDVI) series from satellite remote sensing data collected between 1982 and 2006 over 8-kilometer grid points. In previous research, multiple testing procedures controlling the mixed directional false discovery rate (mdFDR) were used to detect areas with significant increasing or decreasing monotonic vegetation changes based on arbitrarily chosen square regions of land. This paper improves the assignment grid points (pixels) to regions by formulating as a multidimensional temporal assignment problem. Due to the complexity of the formulation, a heuristic approach is proposed using dynamic programming with a penalty/reward function for pixel reassignment. Pixels are assigned to adjacent clusters based on similar characteristics over time. The results of this analysis find a larger number of detected regions than the previous research, while increasing the homogeneity of the regions.

■ HA-15

Thursday, 8:30-10:00 - 307A

Graphs, path and cycles

Stream: Graphs, telecommunication, networks (contributed)

Contributed session

Chair: Tatsuo Oyama

1 - The most inconsistent graph of paired comparisons with ties

Konrad Kułakowski

Comparing alternatives in pairs are the well-known method of ranking creation. The experts are asked to perform a series of comparisons then the final ranking is prepared. As experts do the individual assessments, they may not always be consistent. Inconsistency is understood for example as a lack of transitivity. Hence, if A is more preferred than B, and B is more preferred than C then to maintain consistency also A need to be more preferred than C. A convenient way of presenting pairwise comparisons (PC) is a graph wherein vertices represent alternatives, and the edges represent preferences. Hence, if A is more preferred than B then in the graph there is a directed edge from A to B. Under this assumption each cycle in a graph indicates inconsistency in preferences. In 1940 Kendall et al. suggest that the number of cyclic sub-graphs composed of three vertices (cyclic triads) can be used to determine the level of inconsistency of a finite set of alternatives represented by a tournament graph. For this purpose they calculate the maximal number of cyclic triads that can be contained in n vertex tournament graph. The presented paper extends the concept of tournament graph so it can represent PC with ties, i.e. PC where the result could be a win, a loss and a tie. In addition, the claim is proven about the maximum number of cyclic triads in this graph. The relationship between set cover problem and the most inconsistent extended tournament graph is also provided.

2 - On the geometric-arithmetic index with given minimum degree

Ljiljana Pavlovic, Milica Milivojevic

The geometric-arithmetic index GA of a graph is defined as sum of weights of all edges of graph. The weight of one edge is quotient of the geometric and arithmetic mean of degrees of its end vertices. The predictive power of GA for physico-chemical properties is somewhat better than the predictive power of other connectivity indices. Let G(k,n) be the set of connected simple n-vertex graphs with minimum vertex degree k. In this paper we characterized graphs on which GA index attains minimum value, when number of vertices of minimum degree k is n-1 and n-2. We also gave a conjecture about the structure of the extremal graphs on which this index attains its minimum value and lower bound for this index where k is less or equal to q, and q is approximately 0.0874. For k greater or equal to q and k or n are even, extremal graphs in this set for which GA index attains its minimum value, are regular graphs of degree k.

3 - Path-counting problem and survivability function - Definition, approximation and applications

Tatsuo Oyama, Kazuhiro Kobayashi

We consider the path-counting problem, which asks, given a network, how many paths exist between any pair of two different nodes in a network after deleting an arbitrary number of edges (nodes) from the original network. In a connected network with n nodes, we know there are n(n-1)/2 paths. Defining the edge (node) deletion connectivity function and the expected edge (node) deletion connectivity function separately, we show these functions by applying Monte Carlo simulation technique for various types of network and actual traffic road networks. These functions can be used for measuring the robustness of the actual network-structured systems in the social systems. Then we try to approximate the above functions using what we call survivability function with two parameters. We also illustrate several applications of the survivability function to the fields of engineering and social sciences.

4 - P-cycle and FIPP p-cycle networks design

Irene Loiseau, Agustín Pecorari

A telecommunication network is said to be survivable if it is still able to provide communication between sites it connects after certain component fails, by redirecting traffic to parts of the network where spare capacity has been installed. We want to design minimum cost survivable networks (SCA, Spare Capacity Allocation Problem). Mesh restoration schemes were used in the 1970s and early 1980s. Self-healing ring based topologies were introduced in the late 80s. In the late 90s the p-cycle architecture concept was proposed. This approach is reported to simultaneously provide the switching speed and simplicity of rings with the much greater efficiency for reconfiguration of a mesh network. A single unit capacity p-cycle is a cycle having one spare channel on each span it crosses. It provides one protection path for a failed span on the cycle and it also protects spans that have both end nodes on the cycle but are not on the cycle. This concept was extended to the FIPP (failure independent path protection) architectures where p-cycles are able to protect paths. We proposed models and algorithms for the SCA with p-cycles and FIPP p-cycles. We will focus here on the FIPP problem. We present a new mixed integer programming model and branch and cut method, a constraint programming formulation, a GRASP algorithm with exact local search and a branch-and-price algorithm. We tested them on real networks and artificial ones. The branch-and-cut algorithm showed to be the most efficient

■ HA-16

Thursday, 8:30-10:00 - 308A

Emerging topics in OM

Stream: Game theory and operations management
Invited session
Chair: Kevin Li

1 - Evaluation of a pharmaceutical risk-sharing agreement when patients are screened for the probability of success
Fredrik Odegaard, Reza Mahjoub, Greg Zaric

We analyse a game-theoretic model of a risk-sharing agreement between a payer and a pharmaceutical firm. The drug manufacturer chooses the price while the payer sets the rebate rate and decides which patients are eligible for treatment. The manufacturer provides the payer with a rebate for non-responding patients. We generalize on the existing literature, by making both price and rebate rate decision variables, allowing the rebate rate to be different from 100%, and incorporating two types of administrative costs. We identify a threshold for the expected probability of response for classifying the drug as a mass-market or niche type, and investigate the optimal solutions for both types. We also identify a threshold for the rebate rate at which the net benefits become equal for responding and non-responding patients. Through numerical examples we examine how various parameters impact the drug manufacturer's and the payer's optimal solution.

2 - Service product design and consumer refund policies
Xiao Huang, Dan Zhang

We consider a monopolistic firm selling to heterogeneous consumers who receive imperfect signals on their quality valuations. The firm can customize the product, customize refunds, or customize both. We show that a wide range of product design and refund policies can be optimal depending on consumer valuation heterogeneity and signal quality.

3 - Pricing strategies in a closed-loop supply chain with marketing effort and fairness concerns
Kevin Li, Peng Ma, Jing Ma

By assuming that demand depends on the retailer's marketing effort, we investigate four reverse channel structures depending on who collects used products: a central planner, a manufacturer, a retailer or a third party. Closed-loop supply chain (CLSC) models are established to investigate supply chain member interactions and their impact on supply chain performance. We derive supply chain profitability under both the centralized and decentralized CLSCs and furnish the optimal marketing effort, collection rate and pricing decisions for the supply chain members. We then extend the manufacturer-collection model to address the case when the retailer has fairness concerns.

■ HA-17

Thursday, 8:30-10:00 - 309A

Optimization methods in machine learning

Stream: Nonlinear optimization with uncertainties
Invited session
Chair: Stefania Bellavia

1 - On the employment of inexact restoration for the minimization of functions whose evaluation is subject to errors
Ernesto G. Birgin, Natasa Krejic, José Mario Martínez

Inexact Restoration is a well established technique for continuous minimization problems with constraints. Recently, it has been used by Krejic and Martínez for optimization of functions whose evaluation is necessarily inexact and comes from an iterative process. This technique will be generalized in the present paper and it will be applied to stochastic optimization and related problems. New convergence results will be given and numerical results will be presented.

2 - Coordinate descent converges faster with the Gauss-Southwell rule than random selection
Mark Schmidt

There has been significant recent work on the theory and application of randomized coordinate descent algorithms, beginning with the work of Nesterov [SIAM J. Optim., 22(2), 2012], who showed that a random-coordinate selection rule achieves the same convergence rate as the Gauss-Southwell selection rule. This result suggests that we should never use the Gauss-Southwell rule, because it is typically much more expensive than random selection. However, the empirical behaviours of these algorithms contradict this theoretical result: in applications where the computational costs of the selection rules are comparable, the Gauss-Southwell selection rule tends to perform substantially better than random coordinate selection. We give a simple analysis of the Gauss-Southwell rule showing that—except in extreme cases—its convergence rate is faster than choosing random coordinates. We also (i) show that exact coordinate optimization improves the convergence rate for certain sparse problems, (ii) propose a Gauss-Southwell-Lipschitz rule that gives an even faster convergence rate given knowledge of the Lipschitz constants of the partial derivatives, (iii) analyze the effect of approximate Gauss-Southwell rules, and (iv) analyze proximal-gradient variants of the Gauss-Southwell rule.

3 - Spectral projected gradient method for stochastic optimization
Natasa Krklec Jerinkić, Natasa Krejic

We consider the Spectral Projected Gradient method for solving constrained optimization problems with the objective function in the form of mathematical expectation. It is assumed that the feasible set is convex, closed and easy to project on. The objective function is approximated by a sequence of different Sample Average Approximation functions with different sample sizes. The sample size update is based on two error estimates - SAA error and approximate solution error. The Spectral Projected Gradient method combined with a nonmonotone line search is used. The almost sure convergence results are achieved without imposing explicit sample growth condition. Preliminary numerical results show the efficiency of the proposed method.

■ HA-18

Thursday, 8:30-10:00 - 2101

Location, logistics, transportation and traffic 6

Stream: Location, logistics, transportation, traffic (contributed)
Contributed session
Chair: Ismail Sahin

1 - An integrated approach for the cross-docking and routing problem
Eduardo Delcides Bernardes, Franklina Toledo

Supply chain management entails controlling and integrating different processes between suppliers and consumers. An important supply chain activity is the distribution of products. The cross-docking distribution strategy has been studied and adopted by many companies. The main purpose of this strategy is to reduce costs by eliminating or reducing storage and improving the use of transport capacity allowing for greater product flow and faster deliveries. Depending on the distribution system features, decisions of cross-dock planning need to consider decisions concerning delivery routes. To the best of our knowledge, there are few papers in the literature dealing with cross-dock planning and routing decisions in an integrated way. In our study, we focus on a cross-docking distribution system inspired by a retailer network whose operational planning requires integrating cross-dock internal decisions with routing decisions for distribution. We developed two mathematical models with different ordering constraints for the problem. The first one is modelling based on assignment constraints idea and the second on precedence constraints idea. We evaluated the proposed models using computational tests.

2 - Design challenges and performance analysis of the AGV-pick system
Kaveh Azadeh, Debjit Roy, René de Koster

Several retail warehouses use manual order picking systems. Since retailers stock a large assortment of items, they usually place large replenishment orders with the distribution center. The DCs ship orders in multiple roll cages. Therefore, a picker in the DC does multiple pick cycles (trips between pick locations and the depot) to fulfill a single order. Recently, an AGV-based pick system (also known as AGV Pick) is developed to minimize the pickers travel time for filling large orders. In such systems, the AGVs (Automated Guided Vehicle) automatically follow the picker closely and transport the roll cages for the picker to put away the retrieved items. Once the roll cage is full, the AGV is automatically swapped with a new AGV carrying an empty roll cage. Therefore, the picker can continue with the picking route without returning to the depot, and the AGV automatically transports the full roll cage to the depot. Due to a parallel movement among the pickers and the AGVs, modeling, analysis, and optimization of such systems is complex. In this research, we attempt to develop queuing network models to capture the realistic movement of the AGVs and the pickers in the system and develop solution methods for performance evaluation. We also validate our approach using detailed simulations.

3 - Tests of Markov assumptions using transitions matrices developed for train delay propagation
Ismail Sahin

Train schedules are modified to cope with late movements of trains due to perturbations. Depending on the nature of delay-causing effects and the extent of delays, schedules are modified by either delaying some trains or changing their orders. The effectiveness of these scheduling decisions can be attributed to deviations from the schedule (i.e., delays) at points along the rail line, especially at stations and junctions, where actual departure and arrival times are recorded and compared with the corresponding scheduled times. The pairs of consecutive train departure-arrival and arrival-departure constitute events for determining delay propagation along train paths and can be considered as stochastic processes. Defining the certain delay measures as states and tracing the consecutive delays of a train path help the analyst extract delay transition structure leading to the transition matrix for delay propagation. The transition matrices developed in this manner can be used to determine various performance measures in Markov chain models as well as to make predictions for train movements. This novel approach in scheduling is, however, restricted by Markov assumptions. Before utilizing the developed transition matrices, they should be tested for those assumptions, namely, Markov property and time-stationarity or time-homogeneity property. It will be shown how to perform the tests using some example transition matrices developed for train movements on a single-track railway line.

■ HA-19

Thursday, 8:30-10:00 - 2102AB

Robust optimization: Theory and applications

Stream: Robust optimization
Invited session
Chair: Ihsan Yanikoglu

1 - Decision rule bounds for robust bilevel programs
Ihsan Yanikoglu

We study stochastic bilevel programs where the leader chooses a binary here-and-now decision and the follower responds with a continuous wait-and-see-decision. Using modern decision rule approximations, we construct lower bounds on an optimistic version and upper bounds on a pessimistic version of the leader's problem. Both bounding problems are equivalent to explicit mixed-integer linear programs that are amenable to efficient numerical solution. The method is illustrated through a facility location problem of a market entrant competing with a settled opponent in selling units to the customers with conflicting preferences.

2 - Multistage adaptive binary optimization with applications to R&D process management
Aurelie Thiele

We investigate robust optimization approaches to manage optimally and dynamically the R&D pipeline given revenue targets at different points in time, using concepts from multistage adaptive binary optimization. We consider in-house incremental vs breakthrough innovation and the ability to acquire competitors' R&D portfolios. Theoretical insights and computational experiments are provided.

3 - Radius of robust feasibility in conic linear programming
Miguel Goberna

In this talk we present computable lower and upper bounds, as well as an exact formula, for the radius of feasibility guaranteeing the existence of robust feasible solutions for uncertain conic linear programming problems. The mentioned bounds and the exact formula involve the same two constants (which depend on the chosen base for the cone), and the distance from the origin to the so-called epigraphical set (which depend on the chosen base but also from the data matrix) which are expressed, under mild assumption in terms of the optimal value of computable optimization problems. The talk is based on recent joint research with V. Jeyakumar and G. Li.

4 - Robust optimization and ordered median problems
Justo Puerto

In this presentation, we address some extensions of the robust optimization model by Bertsimas and Sim (Math. Prog. 2003) by replacing the k-sum elements in their model by some general ordered weighted average (ordered median) objectives. We analyze continuous, integer and combinatorial optimization problems and present different formulations of this model that allow to solve it in interesting cases as when it is applied to flow problems, location problems, and some other well-known combinatorial optimization problems such a minimum cost spanning trees, among others.

■ HA-20

Thursday, 8:30-10:00 - 2103

Advances in multi-stage stochastic programming

Stream: Stochastic optimization
Invited session
Chair: Merve Bodur

1 - A discrepancy-based approach for scenario-tree generation
Julien Keutchayan, David Munger, Michel Gendreau

The presentation addresses the question of how to generate efficient scenario trees for solving stochastic programming problems that have a large number of stages and/or a large number of random parameters. We present a framework for designing scenario trees that takes into account not only the probability distribution of the random parameters, but also other important characteristics of the problem, such as its objective function and constraints. This framework is based on the concept of "scenario-tree discrepancy", which provides a generic criterion (or figure of merit) for assessing the quality of a given scenario tree for solving a given stochastic programming problem. In the same way discrepancy is used in quasi-Monte Carlo method for finding good sets of points, our new concept of discrepancy can be used for finding good scenario trees (i.e., appropriate tree structures, discretization points, and weights). Generally speaking, the discrepancy-based approach does not provide a method, but rather a framework to develop methods to design scenario trees. Each one of these methods will be suitable for a given problem or family of problems.

2 - A sequential sampling algorithm for stochastic multi-stage programs
Harsha Gangammanavar

Stochastic Dual Dynamic Programming (SDDP) has become a prominent approach to tackle multistage stochastic programs. The convergence argument for this algorithm rely on existence of finitely many Benders' cuts that can be generated. This is possible only when the probability distributions associated with underlying stochastic processes defining the optimization problem are known, and often represented as a scenario tree. However, in many applications one may not have a priori description of scenarios, and their probabilities. For such cases, the traditional Benders' cuts in SDDP are no longer available, and one has to resort to sequential sampling approach where empirical estimates of the minorants can be calculated. We will discuss convergence of one such sequential sampling algorithm which we refer to as the Stochastic Dynamic Linear Programming. This algorithm is a dynamic extension of the regularized two-stage stochastic decomposition for stagewise independent multistage stochastic linear programs. It turns out that the use of regularization becomes the key to convergence of such algorithms. We will also present results from our computational experiments conducted on a short-term distributed storage control problem. These results show that our distribution-free approach provides prescriptive solutions and values which are statistically indistinguishable from those obtained from SDDP, while improving computational times significantly.

3 - Two-stage linear decision rules for multi-stage stochastic programming
Merve Bodur, James Luedtke

Upper and lower bounds for a multi-stage stochastic linear program (MSLP) can be obtained by restricting decisions in the primal and the dual of the MSLP, respectively, to follow at each stage to be an affine function of the observed uncertain parameters. Such policies are called linear decision rules (LDRs). Finding an optimal LDR is a static optimization problem and, under certain assumptions, can be formulated as an explicit linear program. We propose a new approximation approach for MSLPs, two-stage LDRs. The idea is to require only a subset of decision variables in the primal/dual of the MSLP to follow an LDR, which is sufficient to obtain an upper/lower approximation of an MSLP that is a two-stage stochastic linear program (2SLP). Although solving the corresponding 2SLP approximations is intractable in general, we investigate how approximate solution approaches that have been developed for solving 2SLP can be applied to solve these approximation problems. In addition to potentially yielding better policies and bounds, our approach requires many fewer assumptions than are required to obtain an explicit reformulation when using the standard static LDR approach. When we apply our approach to a capacity expansion model, we find that the two-stage LDR policy has expected cost between 20% and 34% lower than the static LDR policy, and in the dual yields lower bounds that are between 0.1% and 3.3% better.

■ HA-21

Thursday, 8:30-10:00 - 2104A

Cutting and Packing 2

Stream: Cutting and packing
Invited session
Chair: Adriana Cherri

1 - A new column generation approach to the two-dimensional two-stage cutting stock problem
SueJeong Kwon, Kyungsik Lee

We consider a two-dimensional cutting stock problem(2DCSP) where a set of rectangular items to be cut from rectangular stock materials of single size through two-stage guillotine cuts. We propose a novel integer programming formulation based on the 'width pattern' and the 'length pattern'. The strength of its LP relaxation is theoretically weaker than that of the well-known Gilmore-Gomory formulation. However, the column generation problem of the proposed formulation is computationally easier to solve. We presents our computational test results on the benchmark instances in the literature, which show that the proposed formulation is a viable option to solve the 2DCSP.

2 - On cutting stock and pricing for perishable products
Pablo A. Rey, Antoine Sauré, Alejandro Cataldo

We consider the problem faced by a poultry producer and marketer that must determine the processing strategy, inventory levels and price of a perishable product and its subproducts for a given time horizon (usually a week). The company processes whole chickens (raw material) by applying cutting patterns to obtain different subproducts. The resulting quantities must satisfy retailers' demand, which is price dependent. The main decisions in this problem are: the number of times each cut pattern is applied, the levels of inventory for each subproduct in each time period, the list price for each product in the whole horizon, and the daily discount policy on this list price. The aim of the company is to maximize the economic benefit taking into account the perishability of the products, pre-defined cutting pattern, and pre-established pricing policies. Although production and inventory management problems that consider the list price and the discount strategy as decision variables have studied extensively over the last tow decades, to the best of our knowledge, the combined cutting stock and pricing problem seems to have received limited attention. To address this, we propose an approach that uses optimization and dynamic programming problems.

3 - Biobjective approaches for the cutting stock problem minimizing total number of objects and saw cycles
Socorro Rangel, Jesus Saez Aguado

Some decisions associated to the cutting stock problem (CSP) might be taken considering a set of conflicting objectives and in general, there is not a single solution that attends all of them. An example is the definition of a cutting plan that minimizes the total number of objects and minimizes saw cycles. The literature on multiobjective combinatorial optimization is quite extensive, however only a few papers address the multiobjective CSP. In this work we present a biobjective study of the CSP taking into account the minimization of waste and saw cycles. It differs from other works presented in the literature in two main points. The first regards the model used to represent the problem and the second the approaches employed to obtain an approximation of the pareto front, which is done using procedures based on the epsilon-constraint method. We propose three methods to solve the associated lexicographic problem. Preliminary results of a computational study developed using instances from the literature and based on real data indicate that an adaptation of the weighted sum method is the most useful in the search for nondominated solutions, although the subproblems involved are difficulty to be solved.

4 - A stochastic programming approach to the cutting stock problem with usable leftovers
Adriana Cherri, Luiz Henrique Cherri, José Fernando Oliveira, Maria Antónia Carravilla, Douglas Alem

The cutting stock problem with usable leftovers under uncertainty considers that the item demand is uncertain, situation that typically occurs in practice, in many real-world contexts. This demand must be produced by cutting either standard objects or retails, which are leftovers that resulted from previous cutting process and with a sufficient length to be used in the future. When cutting a standard object to attend demand, three situations may occur: there may be no leftover; the leftover may be so small that has future use; or the leftover may be a retail that can be used to cut future demand. Waste may be minimized by explicitly generating retails for future use. However, the length of these retails is important, as it has to meet the future, unknown, demand. Thus, retails are generated considering different future demand scenarios, resulting in a better estimate of the retails' value. A mixed integer programming model is proposed to represent this problem and a column generation approach is developed to solve it. Computational experiments were run and conclusions drawn. Acknowledgement to FAPESP (Proc. n. 2015/03066-8 and 2017/06285-8) for the financial support.

■ HA-22
Thursday, 8:30-10:00 - 2104B

Decision support and applications

Stream: Discrete optimization, mixed integer programming (contributed)
Contributed session
Chair: *Muhammad Asim Qureshi*

1 - Mining candidate solutions to understand the results of an optimization-based decision support system
Michael Morin, Rallou Thomopoulos, Irene Abi-Zeid, Maxime Léger, François Grondin, Martin Pleau

Decision support systems (DSS), in particular optimization-based DSS, are now a common tool in engineering, business, and management. Although optimization-based DSS provide theoretically and/or empirically well-founded solutions to a given practical problem, a user that does not fully comprehend the system's recommendation might simply choose to ignore it. It is therefore becoming more and more important to explain the solutions provided by optimization-based DSS in terms that users can understand. The decision makers can then decide whether to follow or to challenge the DSS's recommendation. This project emerged following a need expressed by our industrial partner to explain the recommendations provided by a commercial software used for real-time decision support for the flow management of a combined wastewater network. In order to address this need, we propose to mine a set of feasible alternatives to a given optimal solution using decision trees. These would allow us to derive simple rules that can be transformed into arguments for or against a proposed solution. In this talk, we present the methodology that we developed and discuss its application to a real case.

2 - CPLEX 12.7 helps you write better models
Xavier Nodet, Daniel Junglas

Version 12.7 of CPLEX, released in December 2016, introduces two new features to help users write better models. With Modeling Assistance, CPLEX displays warnings when the model that it solves has characteristics that may introduce difficulties in the solving process. An example would be a constraint with a very large range of coefficient values, that can lead to numerical trouble for the solver. With 'tools runseeds', a new command in the CPLEX Interactive, a model is solved repeatedly using different random seeds, and statistics are displayed about running time, number of nodes, etc. This allows to evaluate the variability of the solve process for this model, and provides much more accurate information than running the model only once. We introduce these two features, explain their usage, and present examples of models that benefit from using them in terms of better numerical stability, better performance, or both.

3 - A hybrid meta-heuristic algorithm for cut-off grade optimization in open pit mining operations
Muhammad Asim Qureshi, Mohammad Waqar Ali Asad

This research paper illustrates a hybrid meta-heuristics strategy that solves a mixed integer linear programming (MILP) formulation for cut-off grade optimization problem in open pit mining operations. The objective function is to maximize the discounted value (NPV) of future cash flows subject to mining, milling and marketing constraints. The hybrid meta-heuristic combines genetic and ant-colony algorithms. The proposed algorithm is tested for a hypothetical block model and the same data is validated using CPLEX concert technology optimizer. The computational results show that the hybrid algorithm is computationally efficient in achieving optimum solution with relatively minor gap in a majority of the instances. Keywords: Cut-off grade Optimization, Hybrid meta-heuristics, Mixed Integer Linear Programming. Genetic Algorithm, Ant-Colony Optimization.

■ HA-23
Thursday, 8:30-10:00 - 2105

Re-scheduling and OD estimation

Stream: Optimization for public transport
Invited session
Chair: *Marie Schmidt*
Chair: *Evelien van der Hurk*

1 - Rolling stock rescheduling in case of delays
Rowan Hoogervorst, Twan Dollevoet, Dennis Huisman, Gabor Maroti

During the normal operations of a railway operator, disruptions of varying intensity might occur. The existing rolling stock rescheduling literature has mostly focused on large disruptions, such as the unavailability of railway infrastructure. Instead, we focus on rolling stock rescheduling for small disruptions in this research. Specifically, we consider rolling stock rescheduling under delays. This due to the fact that the chosen rolling stock circulation may affect the delay propagation and thus the total delay incurred by passengers, for example by means of the chosen shunting pattern. As current optimization models for rolling stock rescheduling do not incorporate delays, we will present new optimization models for this setting. These presented optimization models are extensions of the currently used flow- and path-based rolling stock rescheduling models. Next to incorporating the delay that propagates from delayed rolling stock, these presented models also reflect the larger set of options that are often available for dispatchers in short-term rescheduling. For example, we relax the requirement of a fixed turning pattern for some of the terminal stations. To evaluate the usefulness of these new optimization models for dispatchers, we furthermore evaluate them on real-life instances from the Netherlands Railways (NS).

2 - The vehicle rescheduling problem with retiming
Dennis Huisman, Rolf Van Lieshout, Judith Mulder

When a vehicle breaks down during operation in a public transportation system, the remaining vehicles can be rescheduled to minimize the impact of the breakdown. In this presentation, we discuss the vehicle rescheduling problem with retiming (VRSPRT). The idea of retiming is that scheduling flexibility is increased, such that previously inevitable cancellations can be avoided. To incorporate delays, we expand the underlying recovery network with retiming possibilities. This leads to a problem formulation that can be solved using Lagrangian relaxation. As the network gets too large, we propose an iterative neighborhood exploration heuristic to solve the VRSPRT. This heuristic allows retiming for a subset of trips, and adds promising trips to this subset as the algorithm continues. Computational results indicate that the heuristic performs well. While requiring acceptable additional computation time, the iterative heuristic finds improvement over solutions that do not allow retiming in one third of the tested instances. By delaying only one or two trips with on average 4 minutes, the average number of cancelled trips is reduced with over 30 percent.

3 - A Benders' algorithm for real-time train routing and scheduling including effective inequalities

Kaba Keita, Paola Pellegrini, Joaquin Rodriguez, Ángel Marín

In railway systems, during congested traffic situations, the infrastructure capacity is completely exploited for ensuring the trains circulation. Hence, when a disruption occurs and the traffic is perturbed, conflicts may occur. Consequently, some trains must be stopped or slowed down for ensuring safety, and delays occur. Modifying trains route and schedule to limit delay propagation is the aim of the real-time train routing and scheduling problem. In this study, we propose a Benders' decomposition of a MILP-based algorithm for this problem, named RECIFE-MILP. Moreover, we include some inequalities in the Benders' master problem to avoid the creation of many slave problem infeasible solutions during the search. In our Benders' decomposition train routing and scheduling decisions are made in the master problem. Given these decisions, we compute the train's actual arrival times in the slave problem to deduce total delays. Computational analysis on instances representing traffic in the Rouen-Rive-Droite control area in France are presented, showing that adding some initial inequalities in the Benders' master problem improves quite substantially the results.

4 - Exploratory analysis of time and spatial patterns in smart card data

Paul Bouman, Evelien van der Hurk, Peter Vervest, Leo Kroon

One of the major challenges for public transport operators is how to deal with peak demands. Peak demands dictate the required vehicle capacity, but the higher the peak demand the lower the utilization of vehicles will be in the off-peak. In order to model which passengers might travel outside the peak-hours it is useful to know temporal and spatial demand patterns. One approach to obtain these patterns is to analyze smart card data, as the introduction of smart card ticketing systems resulted in a wealth of data compared to analogue ticketing systems. In this research we investigate how to define activity patterns that be used to generate synthetic smart card data. We then propose a methodology that can be used to validate methods that extract temporal and/or spatial patterns from smart card data. Finally, we propose a method based on k-means clustering that is able to extract temporal and spatial pattern from large amounts of smart card data. Our validation finds that some demand patterns can be detected effectively, while others are hard to distinguish from other activity types for our methodology. Future methodologies can be evaluated with our dataset and validation method.

■ HA-24

Thursday, 8:30-10:00 - 301A

Hospital planning 2

Stream: CORS SIG on healthcare
Invited session
Chair: Peter Vanberkel
Chair: *Ege Babadagli*

1 - A mixed-integer linear programming optimization model for capturing expert planning style in interstitial low dose rate prostate brachytherapy

Ege Babadagli, Ronald Sloboda, Nawaid Usmani, John Amanie, Albert Murtha, Don Yee, Muhammad Jamaluddin, John Doucette

Low dose rate (LDR) brachytherapy is a minimally invasive form of radiation therapy for prostate cancer that involves the permanent implantation of radioactive sources (seeds) inside of the prostate gland. Treatment planning in brachytherapy consists of a decision making process for the placement of radioactive sources in order to deliver an effective dose of radiation to cancerous tissue in the prostate while sparing the surrounding healthy tissue such as the urethra and rectum. This decision making process may be automated by modelling it as a mixed-integer linear programming (MILP) problem. We introduce a novel MILP optimization model for interstitial low-dose rate prostate brachytherapy that attempts to mimic the qualities of treatment plans produced manually by expert planners. Our approach involves incorporating a unique set of clinically important constraints, called spatial constraints, that enable us to capture the treatment planning style present at a cancer center. Furthermore, we introduce pseudo high-resolution data sets and constraint-violating feasibility-based modelling in order to improve the solution time performance of our model. We demonstrate solution times that are acceptable for pre-operative as well intra-operative planning and range from less than a minute to roughly five minutes for small to large prostates. We also verify the clinical acceptability of our automated plans through a pilot study involving data from twenty patients.

2 - Physician scheduling to improve patient flow through emergency rooms

Farzad Zaerpour, Marco Bijvank, Zhankun Sun

Emergency department (ED) crowding has become a serious concern worldwide. Hours of waiting is the main consequence of crowding in emergency departments. In this study, we develop a mixed-integer stochastic program for scheduling physicians to improve patient flow through an emergency department. Physicians' schedules in emergency rooms have traditionally been built around physicians' preferences, regulatory and work constraints. A more effective method of physician scheduling is a procedure to achieve an overall balance between physicians' productivity and patient arrivals. The operational performance of an emergency department is vulnerable to mismatch between these two factors. Therefore, the proposed model takes into account the stochastic natures of both physicians' productivity and patient arrivals.

3 - Identifying the effect of medical screening examinations on rural hospital emergency department patient flow

Murray Cote

Emergency Department (ED) overcrowding remains a partially avoidable problem due to non-urgent ED visits. The use of affiliated, primary health clinics is a reasonable alternative care setting for non-urgent patients. Four rural hospital-based EDs in Texas implemented a novel medical screening examination (MSE) program in 2011. The MSE was designed to identify non-urgent patients and we were tasked with identifying the effect of the MSE. As a retrospective study, relevant ED visit information were extracted from four rural hospital facilities for the calendar years 2011-13. A phased roll-out approach was used to launch the MSE at the four facilities. The primary outcome measure for this study was the percentage of Emergency Severity Index (ESI) level 4 or 5 (i.e., the two least-severe triage categories) ED arrivals per month. A difference-in-difference approach was performed to compare the percentage ESI level 4 or 5 ED arrivals before and after implementing the MSE. The MSE program offers a promising solution for the ED overcrowding issue, and may be implemented in other rural settings by leveraging available medical care resources. In the long-run, the MSE strategy can help reshape the rural health delivery system and provide less expensive, more effective access to non-emergency healthcare services for rural populations. Ultimately, it may contribute to the accomplishment of the Institute for Healthcare Improvement's Triple Aim for rural population health and outcomes.

■ HA-25

Thursday, 8:30-10:00 - 301B

Managing flammable landscapes under uncertainty

Stream: CORS SIG on forestry
Invited session
Chair: David Martell

1 - Mapping current and future wildfire risk in Canada
Xianli Wang

Wildland fire is ecologically essential for forest health in Canada, but can also be a threat to public safety, forest communities, timber values and infrastructure. Wildland-urban interface fires can result in evacuations, health impacts due to smoke, property loss, and loss of employment and business income. Fire risk assessment is crucial in fuel treatment planning and fire suppression operations, especially when communities and values are at risk. Although wildland fire is influenced by a number of factors (flammable biomass, weather, topography, and ignition sources), the impact of weather is critically important. High intensity, uncontrollable wildfires most commonly occur during extremes in weather. With climate change, extreme periods of weather will occur more often, which may bring more extreme fire occurrence. Developing the spatially explicit and nationally consistent estimates of the current and future fire risk will help fire management agencies identify and prioritize critical at-risk areas, providing guidance for wildfire mitigation programs. Here, we present a framework for developing a series of Canada-wide, baseline fire characteristics (including burn probability, fire intensity and fuel consumption), and fire risk maps for current and future climate change scenarios across Canada. Coauthored by: Xianli Wang, Steve Taylor, Marc-Andre Parisien, Sandy Erni, Chelene Hanes, Mike Wotton, and Mike Flannigan

2 - Spatial fire response optimization
Matthew Thompson, Yu Wei, Erin Belval, Greg Dillon, Jessica Haas

Pre-fire assessment and planning can support incident management decision making by dampening time pressures, reducing uncertainties, expanding options, and clarifying risk-benefit tradeoffs. This presentation will highlight the role of simulation and optimization in spatial fire planning, with an emphasis on factors relating to cost, responder exposure, probability of success, and fire consequences. We will begin by reviewing recent research aimed at pre-identification of potential fire control points (e.g., roads, ridge tops, water bodies) along with their aggregation into polygons called potential wildland fire operation delineations, or PODs. These PODs then form the management unit basis for spatial optimization of larger containers within which to manage an unplanned ignition, with analogous characteristics to other adjacency-driven forest planning problems such as maximum area restriction and minimum patch size. We will present case study results for a forested landscape in western Montana, USA, and illustrate how solution characteristics vary with ignition and fire weather scenarios.

3 - Modeling demand for fire suppression resources
Alex Masarie, Yu Wei, Matthew Thompson, Iuliana Oprea, Erin Belval, Dave Calkin

Efficient and effective wildland fire response requires inter-regional coordination of suppression resources. We fit forward and inverse process models to Resource Ordering Status System (ROSS) requests for nationally-pooled Type I/II hand crews and engines from 2011 to 2015 across the United States. We characterized the performance of demand predictors by examining the regional impact of factors related to ongoing fire activity, suppression resource use, fire weather, expenditures, accessibility, and population density. This talk will outline analogies between the seasonal flow of demand and dynamic models commonly applied to physical processes exhibiting advection, diffusion, and reaction. To orient these mathematical methods in the context of resource allocation, we will present multi-fire management examples varying in scope from local demand interactions on the Holloway/Barry Point/Rush Fires in 2012 to national spatio-temporal trends that emerge in the model under different workload conditions. We will discuss how cognizant prediction of demand for suppression resources facilitates a more efficient supply response.

4 - Evaluating a forest management strategy with respect to uncertain forest disturbance using Monte Carlo simulations
Dirk Kloss, Wenbin Cui

In strategic forest management, natural disturbances such as wildfires are a key uncertainty. Natural disturbance is very difficult to represent in strategy-generating mathematical models, particularly spatially explicit models. Various approaches have been used to make allowance for natural disturbance, including a) ignoring disturbance in strategy development and relying on re-planning if major disturbances occur; b) reducing harvest levels to accommodate potential natural disturbances; c) explicitly representing natural disturbance by assuming constant disturbance levels. None of these approaches account for the disturbance variability which can be huge, particularly in the context of climate change. In the research, we evaluate a base scenario (management strategy) under multiple disturbance scenarios. We used predetermined variable wildfire burn fractions in our linear programming model based on Model III formulation. The variable disturbance by period was generated through sampling from historical burn fraction records. We generated 100 time series of burn fractions and solved the model 100 times then compared results to our base scenario. In this way we can assess the variability of forest management indicators such as harvest volume and area, and levels of silvicultural activities. Thus we can assess the risk of disturbance to forest management.

■ HA-26

Thursday, 8:30-10:00 - 302A

New scheduling models and algorithms

Stream: Scheduling: Theory and applications
Invited session
Chair: Debora Ronconi

1 - Three-stage MILP planning model to support the transport scheduling of light oil derivatives in a pipeline network
Guilherme Schnirmann, Suelen N. B. Magatão, Flávio Neves-Jr, Lucas Bueno, William Hitoshi Tsunoda Meira, Leandro Magatão, Lucia Valéria Arruda

This work proposes a new continuous-time MILP model to support Planning activities in a real-world pipeline network located in Brazil. The proposed model is the input block of a decomposition strategy, which aids the transportation scheduling of light oil derivatives (products with high added-value). The network is composed of 14 areas (4 refineries, 2 harbors, 2 final clients and 6 depots) and 30 bidirectional pipelines, which interconnect those areas, transporting more than 35 derivatives. The related problem is complex (NP-Hard) and the proposed model is part of a solution strategy based on the integration of distinct modules composed of Mixed Integer Linear Programming (MILP) models and heuristic procedures. The main developed modules are the: Planning, Assignment and Sequencing, and Timing blocks. In this work, the Planning Model is responsible for determining total volumes that are transported in a 30-day horizon in the network and the required routes (paths) for this transport. The Planning Model is divided in three stages to better control the influence of each variable in planning and scheduling solutions and to consider some characteristics of the network, for instance: pipeline reverse flow procedures, contaminations between adjacent products, surge tank operations, tank maintenances and degradations. Final scheduling solutions are obtained in a reduced computational time (seconds to few minutes) for real scenarios.

2 - A tire curing scheduling problem
Hector Cancela, Agustín Ghioldi, Sofía Lemes, Pedro Piñeyro, Joaquín Velázquez

FUNSACoop is an Uruguayan cooperative that produces car and truck tires mainly for export. The curing or vulcanization process is the last one in the tire production line, and it is particularly important because it consumes a large amount of energy. Curing consists in putting the "green" tires (made of fabric and rubber) into molds, and subjecting them to high temperatures. Each curing machine can hold up to two molds at the same time, where each mold also imprints the tread designs on the tire. Changing molds imply setup times which must be limited. Due to the factory setup, the energy requirements are the same no matter how many curing machines are used at a given time, so it is important to minimize the total production time. The scheduling problem consists in, given the number of tires to be cured during a shift, deciding the order and number of tires of each type to be processed at each machine (which implies choosing the molds to be used and their changes), to minimize the total production time. Additional restrictions correspond to the number of molds available and the compatibility in processing different tire types. The problem can be considered a variant of the Discrete Lot-Sizing and Scheduling Problem, albeit it has also similarities to Job Shop Scheduling. A MILP formulation was used to solve small instances, but the approach is not scalable; at this moment, we are working in developing heuristic algorithms which can tackle larger real-life instances.

3 - A new network flow model for the minimization of tool switches problem
Horacio Yanasse, Tiago Silva, Antonio Chaves

Consider a set of jobs that need to be processed in a machine. Each job requires a set of tools that must be in the machine's tool magazine in order to process it. The tool magazine has limited capacity, therefore, tool switches may be necessary when processing all the jobs. The Minimization of Tool Switches Problem (MTSP) consists in finding a sequence to process the jobs that minimizes the total number of tool switches. In this work we present a new model for the MTSP based on flows in a network. We present properties of this model and the attempt we made to exploit its structure aiming to have improved computation performance when using it to get a solution.

4 - A biased random key genetic algorithm for the hybrid flowshop scheduling problem
Debora Ronconi, Guilherme Mainieri

This work considers the minimization of the total tardiness in a hybrid flowshop. In this environment, there are stages in series and, in each stage, a number of similar parallel machines. Due to the increasing complexity of production systems, this scheduling problem is often encountered in real manufacturing situations. This problem is approached by a relatively new metaheuristic, known as Biased Random Key Genetic Algorithm (BRKGA). This method uses random keys to represent the chromosomes, does not generate unfeasible solutions, and the term Biased refers to the prevalence of the elite solutions. Several versions of BRKGA were developed in order to exploit features of the best constructive heuristics from the literature such as: scheduling jobs in direct and inverse order, identification of the bottleneck stage, and distinction of the bottleneck stage from the others. Computational experiments were conducted with 432 large problem instances. The methods were compared and the results showed that one of the bottleneck-focused versions stood out against the others. This version achieved better results in 61% of instances; while the best heuristic from the literature achieved 15%. Additionally, in order to find optimal results, a set of 576 small instances was proposed. This experiment indicated that the proposed BRKGA performed well.

■ HA-27

Thursday, 8:30-10:00 - 302B

Behavioural issues in markets and environmental management

Stream: Behavioural OR
Invited session
Chair: Melanie Ayre

1 - Inspection or penalty? An experimental investigation on selling genuine products or counterfeit products
Dong Xie, Xiaobo Zhao, Wanshan Zhu, Jinxing Xie

We consider a seller who can sell either genuine or counterfeit products and study his selling behavior under an inspection policy set by regulators. The policy consists of inspection frequency and penalty. If the seller sells genuine products, he receives a certain payoff. If the seller sells counterfeit ones, he receives an uncertain payoff due to probability of being inspected. To characterize the seller's decision, we build a model assuming perfect rationality and give theoretical conditions for selling genuine or counterfeit products. Based on the above setting, we conducted an experimental study with five treatments to investigate the impact of inspection frequency and penalty on the seller's behavior. Experimental data show that the subjects' decisions deviated significantly from theoretical predictions. Specifically, the subjects still sell counterfeit products with considerable probability, even though the rational decisions are to sell genuine ones; and vice versa. Furthermore, a policy of high inspection frequency and low penalty induces more decisions to sell genuine products than that of low inspection frequency and high penalty. According to these observations, we propose a behavioral model to capture the subjects' decision biases: quantal choice, penalty aversion, and frequency probability weighting. Our results provide insights on how to design an effective inspection policy.

2 - Design and validation of a behaviourally informed forecasting support system
Meysam Arvan, Behnam Fahimnia, Mohsen Reisi, Enno Siemsen

Demand forecasting is a critical task in any business affecting almost all subsequent decisions across the supply chain. Previous research indicates that human judgement is an essential component of demand forecasting. However, unstructured and unguided human intervention into the task could be detrimental to the final forecasts accuracy. Several integrating approaches are introduced to utilise the benefits of the human judgement while hampering its deficiencies and possible biases. Forecasting Support Systems (FSSs) can be potentially used for systematic incorporation of human judgement into demand forecasting process. This study develops a theoretical framework for the design and validation of an adaptive and behaviourally informed FSS. The FSS is built based on the theoretical framework, which is further tested for validation in the Fast-Moving Consumer Goods industry. Essentially, contextual information is incorporated into the proposed FSS to inform the forecaster about the influencing factors. It also features a dynamic guidance system that updates the provided guidance based on the task characteristics and the forecaster's knowledge of the task.

3 - Organizational cultures and the creation of temporary multi-organization for environmental emergency management: Some hints from flashflood emergency in Lorca (Spain)
Raffaele Giordano, Irene Pluchinotta, Alessandro Pagano, Alessandro Pagano

The core activity of deciding and implementing actions in emergency management exceeds the ability of a single centralized entity to cope. The crises response becomes alarge-scale, socio-technical system of individuals, groups, organizations and jurisdictions that need to coordinate their actions for an effective operations. In crises, a "temporary multi-organisation" needs to be deployed, implying difficulties of coordination and shared management of the situation(s). Cooperative response actions need to be carried out in a network form, and can benefit or be impaired by the connectivity patterns of the emergency responders. The existing approaches for enhancing the interaction protocols among emergency responders ignore how cultural diversities (organizational culture, risk perceptions, risk behaviours, etc.) influence the way actors perceive the topology of their own interactional network, and, consequently, their strategies to cooperate with other entities. Neglecting these differences could lead to the development of ineffective procedures, because the actors will not recognize the network through which they collect the information and cooperate as trustable. This work describes a Problem Structuring Methods/Social Network Analysis integrated approach for optimizing the emergency network of interactions accounting for the cultural diversities. The experiences carried out to improve the flash flood emergency management procedures in Lorca (Spain) are described.

4 - Designing a market to generate OR data - An industrial ecology case study
Melanie Ayre, Sarah King, Andrew Reeson

Industrial Symbiosis (IS) is the transfer of wastes and by-products from one firm's manufacturing process to another firm, which uses them as input resources. Many examples of IS have been discovered worldwide, but attempts to design IS relationships have faced many challenges. In theory, an optimisation model could be constructed describing the flows in this circular economy, which would permit a new entrant to identify the best sources and destinations for materials to maximise either individual or system benefit, and we have constructed and tested such a model. In practise the key issue is eliciting the necessary information about potential sources and uses of waste. This information is typically privately held by companies and they have neither the channels nor the incentives to disseminate it. For many jurisdictions and companies, particularly small to medium enterprises (SMEs), there is no viable market for reuse of many wastes. Literature suggests SMEs send 50% of their waste direct to landfill, even though a recycling service provider would charge less than landfill costs. How, then, do we create this market, access credible information, and enable operations research methods such as reverse logistics and hub location to be used for environmental benefit? In this talk, we report on the case study of ASPIRE, which works with local government business networks and self-selected manufacturers and recyclers to create a market for wastes and promote IS.

■ HA-28
Thursday, 8:30-10:00 - 303A

Applications of OR 2

Stream: Applications of OR (contributed)
Contributed session
Chair: *Vladimir Matveenko*

1 - Robust routing for evacuation plan
Shaghayegh Mokarami, S. Mehdi Hashemi

An earthquake is one of the most destructive disasters and experts believe it is very likely that it occurs in Tehran in the near future. Studies show that in an earthquake, most casualties are the result of secondary events like collapse of structures. It is possible that a tremor is a sign of a major earthquake. So one of the most important issues in emergency management is to design a plan to evacuate people to safe places as quickly as possible. We use the network flow over time concepts to define evacuation plan that specifies the number of people and the paths through which individuals are sent to safety in each time step. Due to existence of unexpected events in critical situation, we consider the travel time of arcs as uncertain parameters. We apply the robust optimization framework which has a suitable structure to model uncertainty in evacuation planning. First, the importance of preserving life and properties makes the conservative manner of it acceptable. Second, due to the rare number of natural disaster, the distribution probability function of transit times can be hardly determined. We define the robust quickest transshipment problem with several sources and one sink to design evacuation plan. The aim of the problem is to find the minimum time horizon and also a flow over time which satisfies all the supplies under any scenario. We solve the problem for the district 6 of Tehran. The results show the importance of considering uncertainty to save people.

2 - Efficiency in non-life insurance market in Argentina via data envelopment analysis and its sensitivity to the inputs/outputs selection
Zilla Sinuany-Stern, Gustavo Ferro

This study measures the relative efficiency of the non-life insurance companies in Argentina and its evolution during 2009-2014 via Data Envelopment Analysis. The sensitivity of the efficiency to the inputs/outputs specification is tested in regard to two well-known approaches in the insurance efficiency measurement: Model A by Cummins et al. (1996), and Model B by Luhnen (2009). In Model A the inputs are: Employees, Physical capital, and Financial capital; the outputs are: Losses incurred, and Invested assets. In Model B, the inputs are: Operative costs, Production costs, Financial capital, and Liabilities; the outputs are: Claims paid, and Invested assets. Overall data from 83 companies was used over 6 years. As the number of inputs/outputs increases the efficiency and number of efficient units increase; as found for model B which has one more input. Over time, in both model the average efficiency of the companies decreased from 2009 till 2012, and increased afterwards. However, Model A's average efficiency is maximal at 2009, while Model B at 2014. In model A none of the companies was efficient every year, and 58 were not efficient in any of the years; while in Model B, 3 companies were efficient every year and 58 companies were not efficient in any year. In 2014 we found 14 efficient companies by both models, and 45 non-efficient companies by both models. Overall we found significant dependence between the two models in 2014 and over time.

3 - Bi-objective multiple criteria data envelopment analysis model combined with optimization via Monte Carlo simulation applied to a steel industry in Brazil
Fernando Marins, Aneirson Silva, Erica Dias, Marcelo Figueiredo

Quality control is one of the main pillars for a good yield of a production line, aiming to guarantee greater efficiency, effectiveness and reduction of production costs. The identification of causes of defects and their control are relatively complex activities due to the many variables present in certain processes. This work was developed in a large steel industry in Brazil which operates in the production of railway and industrial components, and the objective is to reduce casting defects. From the database, available in the company studied, the efficiency of the production process involving seven products and 38 process variables of these products was evaluated. In this efficiency analysis, the Bi-Objective Multiple Criteria Data Envelopment Analysis (BiO-MCDEA) model was adopted, and the inputs and outputs process variables that are important for the improvement of the efficiency of the production process were evidenced. Based on this set of variables identified by the BiO-MCDEA model, empirical functions were developed through multiple nonlinear regression to represent the productive process of industrial and railway castings. Finally, it was performed an optimization via Monte Carlo simulation to determine the best fit in the variables selected as being relevant by the BiO-MCDEA model. The results obtained for the production process were interesting and were validated by specialists of the company studied.

4 - Network analysis based on a typology of nodes
Vladimir Matveenko, Alexei Korolev

Commonly in network analysis and its economic and social applications a network (non-oriented graph) is represented by its adjacency matrix which may have an enormous order. However, in many cases instead of the adjacency matrix a reduced matrix (which will be referred as type adjacency matrix) may be used. We provide a definition of the types of nodes and the type adjacency matrix, propose an algorithm for division of the set of nodes to types and construction of the type adjacency matrix, and study its properties and applications. The set of nodes of network may be decomposed into S disjoint classes in such way that any nodes belonging the same class have the same numbers of neighbors from each class. The classes will be referred as types of nodes. Type j is characterized by the vector of the numbers of neighbors of any node of class j in different classes. We construct a new matrix T of order S referred as type adjacency matrix of the network. The type adjacency matrix T can be used instead of the adjacency matrix M for many purposes: calculation of the vectors of eigenvector centralities, Katz-Bonacich centralities and alpha-centralities, research of game equilibria in economic models on networks. An example which we study in details is the network game model of production with knowledge externalities.

■ HA-29

Thursday, 8:30-10:00 - 303B

Power systems planning and uses

Stream: Long term planning in energy, environment and climate
Invited session
Chair: *Edi Assoumou*
Chair: *Nadia Maïzi*

1 - Developing systematic innovation principle to resolve the structural paradox of nuclear-free homeland
Yi-Chun Chen, Dong Shang Chang, Chun-Cheng Chen

After suffering the nuclear disaster of Fukushima in Japan, the energy policies and the safety of nuclear power generation have been revisiting by many countries in the world. In order to efficiently respond this issue, the government in Taiwan addressed new energy policies toward a Nuclear-Free Homeland in 2025, which include exploring renewable energy, improving power generation efficiency, reducing carbon with saving energy and implementing electricity liberalization. However, the initiating energy policies results in the structural paradox of contextual complexity among the economic, environmental and social dimensions. Therefore, this study firstly employs "Theory of Inventive Problem Solving (TRIZ)" to develop systematic innovation principle for resolving the structural paradox of the energy policy. Secondly, the systematic innovation principle of Nuclear-Free Homeland will be further evaluated by the Multiple Criteria Decision Making (MCDM) method, which is the Decision Making Trial and Evaluation Laboratory (DEMATEL) for identifying the causal relationship and degree of key influence among the innovation principles. The research result of this study will propose the key decision guidelines for helpfully fulfilling the prospect of nuclear-free homeland in Taiwan.

2 - Optimization problem for power flow controller
Takayuki Shiina, Jun Imaizumi, Chunhui Xu, Susumu Morito

In power delivery systems, the use of dispersed generation and security control to improve network utilization requires the optimal use of system control devices. The installation of loop controller allows the distribution system to operate in a loop configuration, achieving effective management of voltage and power flow. In the investment planning process, it is important to identify the optimal location and installed capacity of the equipment such that all operational constraints are satisfied. The installation of equipment is formulated as an integer programming problem, but because the calculation of flow is a nonconvex nonlinear programming problem, a solution is difficult to find. This paper presents a method for identifying the optimal location and capacity with the minimum installation cost. Our novel approach uses an economic model that considers the fixed costs. A slope scaling procedure is presented, and its efficiency is demonstrated using numerical experiments.

3 - Energy vehicle routing problem for differently sized and powered vehicles
Herbert Kopfer, Benedikt Vornhusen

Electric vehicles (EVs) and combustion-powered vehicles (CVs) differ substantially with respect to several characteristic factors that have major impacts on vehicle routing. EVs are more energy efficient than CVs, but they have a smaller driving range, and compared to CVs with the same gross weight, they have a lower payload. In this contribution, various vehicle fleets with differently sized EVs and CVs are considered for vehicle routing. First, EVs are opposed to CVs. Second, the effect of increasing the battery capacity of EVs is investigated. Third, the characteristics of mixed fleets are analyzed. The computational results are generated by solving a MIP formulation of the introduced Energy Vehicle Routing Problem with Time Windows, Recharge Stations and Vehicle Classes (EVRPTW-R-VC) by means of a commercial solver.

4 - The long term potential for electricity and gas grids integration in France
Edi Assoumou, Rémy Doudard, Jerôme Gutierrez

To respond to the sustainability challenge, future electric systems are expected to be essentially based on low carbon solutions and also to be more flexible in order to balance supply and demand with more variable renewables. Among the options to achieve these goals a higher integration of electricity and natural gas grids could be beneficial. The operational reactivity of gas power plants could help balance the intermittency of solar and wind. Conversely, in a power to gas mode, excess electricity could be stored as hydrogen in the gas grid or even converted to synthetic methane using captured carbon dioxide. In this study we will focus on the condition of such an interaction for the future French power system by 2050. Using a LP framework to model the electricity and gas supply/demand problem, we will discuss investment and operational decisions (at an hourly resolution) for representative days and seasons.

■ HA-30

Thursday, 8:30-10:00 - 304A

Healthcare service delivery and analytics

Stream: Health care management
Invited session
Chair: *Yong-Hong Kuo*

1 - Overbooking decisions for balancing direct and indirect time in healthcare
Yan Chen

Difficulty in providing timely access to medical care is a very common challenge worldwide, especially for public health care. Empirical studies show that long indirect waiting time (appointment delay) does not only lead to deterioration of patient health, but also result in rises of patient no-shows. All together, it brings the service provider into a stressful conflict situation where resources are underutilized while patients have long waits in getting appointments. This study investigates how overbooking level can be manipulated to maintain desirable levels of indirect and direct waiting time for a healthcare service provider, where the probability of show-up is an empirical function of appointment delay. An empirically calibrated simulation model is developed and employed to understand the dynamics among indirect waiting, direct waiting and overbooking level.

2 - Improving access to radiation therapy treatment through enhanced patient appointment scheduling
Nathan Horvath, Claire Ma, Ingeborg Bikker, Martin Puterman, Antoine Sauré, Scott Tyldesley

Wait times are a significant problem in healthcare. In radiation therapy, waits may translate into loss of local control of cancer and deterioration of quality of life. Wait times are often a consequence of an imbalance between capacity and demand, but also result from inefficient patient scheduling. Highly variable demand, complex treatment fractionations, varying machine requirements and patient preferences, together with limited treatment capacity, make it extremely difficult for a booking agent to manually assess the impact of his/her decisions on the efficiency of capacity allocation. This unintended lack of foresight may translate into unnecessary delays, a non-systematic prioritization of patients, unused capacity and excessive overtime. We develop an integrated decision support framework for radiation therapy appointment scheduling consisting of two parts. The first part assigns treatment dates and units to incoming patients, using policies derived from a discounted infinite-horizon Markov model. The second part then assigns specific appointment times within each treatment date, using a mixed integer programming model. This framework provides a systematic way of allocating treatment capacity to incoming demand while improving patient satisfaction and service levels in a cost-effective manner. The benefits of the proposed approach are evaluated by simulating its performance in a practical scenario based on data provided by the British Columbia Cancer Agency.

3 - Improvement of operation process for healthcare workers with wearable sensors at an elderly day care facility in Japan

Masato Takanokura, Yuta Shimosako, Koki Karube, Munenori Kakehi, Tetsuo Yamada

The operation process of healthcare workers was analyzed in an elderly day care facility with rehabilitation in Japan, and improvement of healthcare operations was discussed in terms of the professional duty for elderly care. Three healthcare workers with different duties participated in this study. Their operation process was recorded manually, and the healthcare operation was classified into care and non-care activities, moving, waiting, and rest. Care and non-care activities were classified into sub-groups: main, hospitality, and set-up tasks. In addition to the operation process, we measured two physiological data, which were heart rate and physical activity, from the healthcare workers simultaneously. Physical workload could be estimated from the physiological data. Thus, we could plan the operation process with high efficiency and low workload by estimating cumulative workload with physiological data. The worker A had a lot of tasks as the director of this facility. He had a higher workload than the other workers because of many moving operations for facility management. He took care of elderly users with walking around and managed healthcare services entirely in the facility simultaneously. The other workers B and C showed that their workload was task-dependent and smaller than that of the worker A. We could propose some improvements from the operation process for healthcare workers with wearable sensors such as reduction of unnecessary moving to telephone calls.

4 - RFID analytics for hospital ward management

Yong-Hong Kuo, Chun-Hung Cheng

In this talk, we present an RFID-enabled platform for hospital ward management. Active RFID tags are attached to individuals and assets in the wards. Active RFID readers communicate with the tags continuously and automatically to keep track of the real-time information about the locations of the tagged objects. The data regarding the locations and other transmitted information are stored in the ward management system. This platform enables capabilities of real-time monitoring and tracking of individuals and assets, reporting of ward statistics, and providing intelligence and analytics for hospital ward management. All of these capabilities benefit hospital ward management by enhanced patient safety, increased operational efficiency and throughput, and mitigation of risk of infectious disease widespread. A prototype developed based on our proposed architecture of the platform was tested in a pilot study, which was conducted in two medical wards of the intensive care unit of one of the largest public general hospitals in Hong Kong. This pilot study demonstrates the feasibility of the implementation of this RFID-enabled platform for practical use in hospital wards. Furthermore, the data collected from the pilot study are used to provide data analytics for hospital ward management.

■ HA-31

Thursday, 8:30-10:00 - 304B

OR in regular study programs

Stream: Initiatives for OR education
Invited session
Chair: *Gordon Dash*
Chair: *Nina Kajiji*
Chair: *Gerhard-Wilhelm Weber*
Chair: *Sadia Samar Ali*

1 - Collaborative learning strategy in enhancing the analytical performance of tertiary students in calculus III

Milagros Baldemor

This study determined the degree of performance enhancement of the second year Bachelor of Science in Mathematics students enrolled in Calculus III during the first semester of school year 2015-2016 using the collaborative learning strategy together with anticipation-reaction guide particularly in the applications of integration. Furthermore, it determined the profile of the respondents as to learning styles, attitude towards the subject and previous grades in lower Calculus. The study employed the pretest-posttest experimental design using two equivalent groups: the experimental group exposed to the collaborative learning strategy and anticipation -reaction guide and the control group exposed to the conventional teaching method. The difference in the pretest-posttest scores and their performance in the formative activities and the relationship between their profile and performance was also determined. Findings showed differences in their learning styles and attitudes towards the subject. Significant difference was reflected in the pretest and posttest scores of both groups, their posttest scores and the results of their formative activities. In addition, there was no significant relationship between their learning styles and attitude to their performance but a significant relationship was posted between their performance and their previous grades in lower Calculus.

2 - Active and experiential learning in the advanced quant-FIN classroom

Nina Kajiji, Gordon Dash

Contemporary quantitative and mathematical finance pedagogy, or quant-fin, is evident in courses like 'Financial Derivative Theory'. Quant-fin courses typically include both mathematical and capital market theories. But often this interdisciplinary content reduces to the tedious use of programmable pricing formulae, operational research methods and graphing theory. To encourage theory to practice learning, these courses seek to incorporate experiential teaching techniques. This presentation describes and demonstrates best use of the WinORSe-AI 2017 (WinORS) software system to create an experiential and 'Active Learning' classroom environment. WinORS uses customizable fetches of real-time equity, options, futures and fixed-income data, so that each student team can construct and maintain priced equity and bond portfolios. Investor market volatility forecasts are generated from the same data. Here students evolve models based on the embedded 'Big Data' neural network system. Simulation methods position students to examine option spreads (e.g., collars, straddles, gut, etc.). The end-of-term capstone output is a report and a research-style poster where each document presents graphical analysis (e.g., the efficient frontier) and how the insertion of option spreads converts the equity/bond portfolio to a long-short hedge fund. Lastly, using the WinORS on-line automated trading system students compare risk-adjusted performance across all alternate risk-mitigation methods.

Thursday, 10:30-12:00

■ HB-01

Thursday, 10:30-12:00 - 307B

Financial modeling 2

Stream: Decision making modeling and risk assessment in the financial sector
Invited session
Chair: *Efsun Kürüm*
Chair: *Zrinka Lukac*

1 - Coupon bond duration and convexity analysis: A non-calculus approach
Zrinka Lukac, Vedran Kojic, Margareta Gardijan

Bond duration and convexity are the primary risk measures for bonds. An analysis of coupon bond duration and convexity has been widely covered in the existing literature, with calculus being used as the dominant approach. On the other hand, some authors have treated coupon bond duration and convexity without the use of differential calculus. However, they did not provide a complete analysis of bond duration and convexity properties. Therefore, in this talk we fill in the missing gap. Since the application of calculus may be complicated or inappropriate if the functions in question are not differentiable (as indeed is the case with the bond duration and convexity function), here we prove the properties of bond duration and convexity function by using only elementary algebra. This provides an easier way of approaching this problem, thus making it accessible to wider audience who is not necessarily familiar with tools of mathematical analysis. Finally, we illustrate the properties of these functions by using empirical data on coupon bonds.

2 - Valuation of Israeli options using a projected successive over relaxation algorithm
Aloagbaye Momodu, Chi-Guhn Lee

Israeli options are an extension of the American options, with which the seller has the right to cancel the contract at any time before maturity at a pre-specified penalty. The valuation of an Israeli option requires the computation of an equilibrium value of an optimal stopping game between the buyer and the seller. Specifically, the equilibrium value should ensure the buyer pays the fair price for the contract while the seller sells the contract for the fair price which can be invested in a self-financing portfolio with returns equivalent to possible future payments to the buyer at the exercise or cancellation of the contract. The existing literature has focused more on theoretical reviews of Israeli options but lacked practical algorithms to evaluate the fair price for Israeli options with finite maturity. We devise a projected successive over relaxation algorithm with two obstacles: one from the buyer and the other from the seller perspective. The algorithm presented here is a more accurate and efficient way to value Israeli options with finite maturity. We also present numerical studies on how interest rate, volatility, penalty value, and maturity affect Israeli option values.

3 - A semi-parametric contingent claims default forecasting model
Zenon Taoushianis, Christakis Charalambous, Spiros Martzoukos

A fundamental limitation of structural models for the estimation of the probability of default is that due to their functional-specific form, they do not optimally fit the data like typical empirical models do. In this paper we propose a methodology where noisy input variables to the model, such as the value of assets and the volatility of assets, are adjusted on the data and used in the structural model, yielding a semi-parametric model. In this context, the Black-Scholes-Merton model is used as a paradigm. Results show an improvement in the performance when comparing our model with other approaches for default prediction, such as a logit model and the traditional Black-Scholes-Merton model, over a one-year forecasting horizon. Most importantly, results are consistent not only in-sample but also out-of-sample and in several cases the improvement in model performance is substantial.

4 - Momentum and density forecasting
Jose Faias, Duarte Stokes

We fit 800 time series models to daily momentum returns in an out-of-sample exercise. We apply the Akaike Information Criterion for model selection and we forecast the one day-ahead probability density function. Our findings show that a skewed and heavy-tailed density performs best, while a simple GARCH(1,1) specification for the conditional variance is picked most often. Furthermore, a strategy designed to have an exposure to momentum which is linear in the one day-ahead Sortino ratio forecast generates a positive and significant annualized four-factor alpha.

■ HB-02

Thursday, 10:30-12:00 - 308B

Metaheuristics for routing problems

Stream: Metaheuristics - Matheuristics
Invited session
Chair: *Andreas Reinholz*
Chair: *Weiqi Li*

1 - Insights on the integration of local search in a large neighborhood search heuristic for the dial-a-ride problem
Kris Braekers, Yves Molenbruch

The Dial-a-Ride Problem (DARP) is a vehicle routing problem considering the transportation of people between individual origin and destination locations. Typically, a time window on pickup or delivery, and a maximum ride time are imposed to ensure the quality of service. The goal is to find a set of minimum cost routes for a set of capacitated vehicles such that all transportation requests are fulfilled. In the past, mainly metaheuristic methods based on Local Search (LS) provided good results for the DARP (e.g., VNS, Threshold Accepting). More recently, several hybrid methods, combining aspects from different heuristic approaches, have been successfully proposed (e.g., Evolutionary LS, GA+LS, ALNS + intra-route LS), a trend which is observed in general vehicle routing literature as well. In this work, we provide some experimental results on a similar hybridization approach: integrating inter- and intra-route LS in an ALNS heuristic. Although the idea as such may not be new, both methods can be combined in several ways. We intend to provide some insights by comparing different hybridizations, using relatively simple components for both methods. Our goal is to answer two research questions: 1) Can we provide any general guidelines on how to best integrate LS in an ALNS framework? 2) Can a simple hybrid algorithm, using simple components for each method, compete with more complex (hybrid) methods?

2 - Iterated local search and simulated annealing algorithms for the inventory routing problem
Aldair Alvarez, Pedro Munari, Reinaldo Morabito

We present two metaheuristic algorithms based on Iterated Local Search and Simulated Annealing for solving the Inventory Routing Problem. This problem consists of defining the customer visit schedule, the delivery quantities and the vehicle routing plan to meet the demands of a set of customers over a given time horizon. We consider the variant with a single item, a single supplier, multiple vehicles and a finite multi-period planning horizon. In addition, we address two different objective functions. The first minimizes the sum of the inventory and travel costs, whereas the second minimizes the logistic ratio, defined as the total travel cost divided by the total quantity delivered to customers. The second objective function, while more realistic in some logistics settings, poses a challenge for integer programming formulations and exact methods because of its nonlinearity. Computational experiments show that the proposed algorithms provide reasonably good quality solutions in relatively short running times for both objective functions when applied to problem instances from the literature. Moreover, the algorithms produce new best solutions for some of these instances.

3 - Comparison of trajectory-based metaheuristics for the electric vehicle routing problem
Rodrigo Linfati

The electric Multi-Depot Vehicle Routing Problem (eMDVRP) is a variant of the classical MDVRP problem, with additional constraints related to the use of electric vehicles; the vehicle can travel a limited distance from the depot, but the vehicle can go to a "recharge point" where it can be recharged (totally or partially) to increase its maximal distance. A review of scientific papers with "electric" VRP problems is included. The classical neighborhoods (for example, 2-opt) easily leads to an infeasible solution, and then we will focus on select and develop a new set of good neighborhoods for this problem. Efficient neighborhoods are presented and used in Simulated Annealing, Tabu Search, and Variable Neighborhood Search metaheuristics. The proposed approaches use the granular search space, based on the use of drastically restricted neighborhoods, not containing the moves that involve only elements that are not likely to belong to good feasible solutions, reducing the computing times. Additionally, to verify the correct implementation of the algorithms are considered instances from the VRP and MDVRP, comparing the solution quality and execution time.

4 - Solution attractor of local search system for the traveling salesman problem
Weiqi Li

Although both the TSP and local search have huge literature, there is still a variety of open problems. The study of local search for TSP continues to be an interesting problem in combinatorial optimization and computational mathematics. We study local search for the TSP from the perspective of dynamical systems and treat a local search system as a discrete dynamical system. The attractor theory in dynamical systems provides the necessary and sufficient theoretical foundation to study the search behavior of local search system. In a local search system, all search trajectories converge into a small region of the solution space, called solution attractor. We will describe a procedure for constructing solution attractor of a local search system for TSP. This procedure can be used to build an attractor-based search system to solve the TSP and its variations. The benefits of the attractor-based search system include (1) the search result is guaranteed to be optimal, and (2) all best solutions can be found if the TSP instance is multimodal. We will also present our empirical study on some important properties of the solution attractor, including convergence of local search trajectories, the size of the solution attractor, and quality of the tours in the solution attractor.

■ HB-03

Thursday, 10:30-12:00 - 200AB

Keynote speaker: Asuman Ozdaglar

Stream: Keynote sessions
Keynote session
Chair: Karla Hoffman

1 - Incremental methods for additive convex cost optimization
Asu Ozdaglar

Motivated by machine learning problems over large data sets and distributed optimization over networks, we consider the problem of minimizing the sum of a large number of convex component functions. We study incremental gradient methods for solving such problems, which process component functions sequentially one at a time. We first consider deterministic cyclic incremental gradient methods (that process the component functions in a cycle) and provide new convergence rate results under some assumptions. We then consider a randomized incremental gradient method, called the random reshuffling (RR) algorithm, which picks a uniformly random order/permutation and processes the component functions one at a time according to this order (i.e., samples functions without replacement in each cycle). We provide the first convergence rate guarantees for this method that outperform its popular with-replacement counterpart stochastic gradient descent (SGD). We finally consider incremental aggregated gradient methods, which compute a single component function gradient at each iteration while using outdated gradients of all component functions to approximate the global cost function gradient, and provide new linear rate results. This is joint work with Mert Gurbuzbalaban and Pablo Parrilo.

■ HB-04

Thursday, 10:30-12:00 - 202

Performance improvement in derivative-free optimization algorithms

Stream: Derivative-free optimization
Invited session
Chair: Sébastien Le Digabel

1 - Order-based error for managing ensembles of surrogates in derivative-free optimization
Sébastien Le Digabel, Bastien Talgorn, Michael Kokkolaras, Charles Audet

We investigate surrogate-assisted strategies for derivative-free optimization using the mesh adaptive direct search (MADS) blackbox optimization algorithm. In particular, we build an ensemble of surrogate models to be used within the search step of MADS, and examine different methods for selecting the best model for a given problem at hand. To do so, we introduce an order-based error tailored to surrogate-based search. We report computational experiments for analytical benchmark problems and engineering design applications. Results demonstrate that different metrics may result in different model choices and that the use of order-based metrics improves performance.

2 - Modified spectral simplex gradient method for unconstrained optimization
Milagros Loreto, Ana Luisa Custodio

In a recent paper, the Spectral Simplex Gradient Method (Spec-Simplex) was introduced to solve non-smooth derivative-free unconstrained optimization problems. Numerical experiments showed that this method was very efficient in terms of number of function evaluations required and quality of the final solution generated. Nevertheless, there are cases where the computational cost is still prohibitive, given the target problem class. In this work, we present a modified Spec-Simplex in which the total number of functions evaluations required is reduced by reusing the previously computed simplex gradients. We will detail the conditions that allow this procedure and illustrate the numerical behavior of the modified version, presenting and discussing encouraging numerical results on a set of non-smooth test functions.

3 - Multi-objective black-box optimization using a hybrid method combining accelerated random search with a direct search method
Rommel Regis

This talk presents a hybrid method that combines a multi-objective extension of the Accelerated Random Search (ARS) algorithm by Appel, Labarre, and Radulovic (2004) with a direct search method. The ARS algorithm for single-objective optimization has been proven to converge to the global minimum faster than the classic Pure Random Search (PRS) algorithm. Moreover, numerical experiments show that a multi-objective extension of ARS, called MARS, consistently outperforms a multi-objective extension of PRS on test problems. Furthermore, under certain conditions, MARS can be shown to capture the Pareto front in a probabilistic sense. In the proposed hybrid method, the nondominated sample points generated by MARS are used to generate starting points for the direct search method. In the numerical experiments, MARS with and without surrogates is combined with Direct Multisearch (DMS) by Custodio et al. (2011) and the resulting hybrid algorithms are compared with alternative methods including NSGA-II, MARS and DMS on a series of test problems for multi-objective optimization.

■ HB-06

Thursday, 10:30-12:00 - 204A

Community-based operations research

Stream: Problem structuring interventions
Invited session
Chair: *Michael P Johnson*
Chair: *Pamela Sydelko*

1 - Towards an understanding of rich picture interpretation for, by and with community in operations research
Tessa Berg, Simon Bell, Steve Morse

A major requirement in community operations research (OR) is for procedural means whereby community can be part of the OR. There is rich literature around the engagement of community in OR but generally this constitutes community as object of study and stakeholder not as integral part of the research process. Reasons for this are manifold. Research practice is not readily transferable and research outcomes interpretation is often a highly skilled process. Whilst not seeking to suggest a panacea this paper considers the value of the Rich Picture (RP) - not just as a means to capture social and technical data- but as a means to allow community 'in' to the research process in a meaningful way. Firstly we review the issues faced in RP interpretation. We discuss the principles of Content Analysis (CA) as a means to interpret visual outputs and discuss the manner in which RPs have been applied in a series of UK, European and Global research projects, with an especial focus on practice within more disadvantaged and marginalised communities. Our key claim to contribution and innovation is in the development of CA via Eductive Interpretation - a means to allow RP CA to emerge systemically from group contexts by unravelling complex stakeholder understandings. Finally we discuss how CA can be applied to enhance the grounding of problem structuring at the level of the group, team or community.

2 - From social impact to propensity to produce social innovation
Maria Franca Norese

When the Municipality of Turin decided to invest in social innovation, involved some public and private incubators and organizations of the social economy and non-profit contexts. A public program and a network of the partners were created, Turin Social Innovation (TSI), and a procedure supporting social innovation start-ups was applied for the first time in 2014. Several projects of young social entrepreneurs have been funded when the Municipality activated a monitoring process. The Social Economy Office (SEO) of the Chamber of Commerce, a TSI member, was asked to participate in the process and, specifically, to evaluate the social impact of the funded start-ups. In that period I was a member of the SEO council and participated in the meeting with the Municipality. The invitation to evaluate the social impact was denied, above all because some months of project implementation cannot produce social impact. My proposal to evaluate a propensity to produce social innovation in the first steps of project implementation was accepted and I was involved in the study. Two methodological approaches, actor network analysis and multicriteria analysis, were combined to analyze the start-up behaviors and to evaluate if they could address social needs, in their specific fields, and develop business projects for an inclusive and sustainable economy. The adopted multimethodology and its results, in relation to the Municipality monitoring and decision processes, will be presented.

3 - Participatory problem structuring methods for generating common interagency understandings of wicked problems
Pamela Sydelko

Wicked problems, by their nature, slice across the bureaucratic boundaries of governments and have many stakeholders with different and sometimes conflicting perspectives. Because these complex problems are characterized by their strongly interdependent elements, it is difficult to anticipate how changes to one part of the problem cause second, third, or fourth order effects on other parts. Governments are trying to find ways to reach across agencies and partner organizations for more integrated approaches to addressing these highly complex problems. Common vehicles for interagency approaches are federal committees, task forces, fusion centers, and workforce exchanges. These constructs could be much more effective if the wicked problem being addressed could first be systemically mapped from the multiple perspectives of the various stakeholders involved. This presentation will describe the use of participatory problem structuring methods (PSM), within an action research context, to engage multiple government agency stakeholders in developing a common understanding of transnational organized crime and urban gangs engaged in trafficking illegal drugs. It will also explore how systems maps generated by the PSM can be used to (1) design organizations that are better aligned with and adapted to the problem and (2) inform a strategy for integrating technologies and infrastructures into more holistic systemic approaches to addressing the problem.

■ HB-07

Thursday, 10:30-12:00 - 204B

Exact methods for routing 1

Stream: Vehicle routing
Invited session
Chair: *Borzou Rostami*

1 - A branch-and-cut algorithm for the capacitated routing problem with profits and service level requirements
Christos Orlis, Demetrio Laganà, Wout Dullaert, Daniele Vigo

We propose the Capacitated Routing Problem with Profits and Service Level Requirements (CRPPSLR) inspired by a real-life case. The CRPPSLR extends the class of Routing Problems with Profits by considering customers requesting deliveries to their service points. Moreover, each customer imposes a service level requirement specifying a minimum-acceptable bound on the fraction of its service points being delivered. A customer-specific penalty is incurred to the Logistics Service Provider when this requirement is not met. The CRPPSLR consists of finding vehicle routes maximizing the difference between the collected revenues and incurred transportation and penalty costs in such a way that vehicle capacity and route duration constraints are met. A fleet of internal and external homogeneous vehicles is available for serving the customers. We design a branch-and-cut algorithm and we identify valid inequalities that have been effectively used for the Capacitated Vehicle Routing Problem and for other Routing Problems with Profits. A real-life case study highlights the relevance of the problem under consideration and computational results illustrate the performance of the proposed solution approach.

2 - A branch-cut-and-price algorithm for the distance constrained multi-depot vehicle routing problem
Ruslan Sadykov, Artur Pessoa, Eduardo Uchoa

In this work we propose a new Branch-Cut-and-Price algorithm for the distance constrained multi-depot vehicle routing problem. The algorithm combines many state-of-the-art techniques known to be efficient for routing problems : bi-directional ng-path based labelling algorithm to solve the pricing problem, generation of limited memory rank-1 cuts with up to 5 rows, reduced cost fixing of arcs, enumeration of elementary routes, and multi-phase strong branching with pseudo-costs. The main contribution of this work is an improvement of the labelling algorithm for the resource constrained shortest path problem with two resources. The labels with similar resource consumption are stored in buckets which are organised in so-called bucket graph. This organisation allows one to significantly reduce the number of dominance checks, exploit route symmetry, and perform reduced cost fixing of bucket arcs. Experiments showed that our algorithm is able to solve to optimality several open instances of the problem with up to 216 customers within the 2 hours time limit. The improvement of the solution time over the recent state-of-the-art algorithm by Contardo and Martinelli (2014) is up to two-three orders of magnitude.

3 - Branch-price-and-cut for the p-step formulations of vehicle routing problems
Pedro Munari

The p-step formulation generalizes many classical vehicle routing problem models. It is based on partial paths that traverse up to p arcs in the network. For the special cases of p=1 and p=n+1 we obtain the well-known two-index vehicle flow formulation and the set partitioning formulation, respectively. For different choices of p, we have different features regarding the linear relaxation bounds, quality of feasible solutions and computational times to generate routes. In this talk, we review this family of formulations and propose an interior point branch-price-and-cut method for them. We address different ideas to deal with the additional capacity and time constraints that appear in the master problem formulation and show how to adapt the labelling algorithm as well the pulse algorithm to generate columns. We present computational results using the Solomon's instances of the vehicle routing problem with time windows.

4 - The vehicle routing problem with stochastic and correlated travel times
Borzou Rostami, Guy Desaulniers, Fausto Errico, Andrea Lodi

Nowadays capabilities in terms of data collection and analysis enable us to accurately describe the nature of random processes. This stochastic information can be advantageously used in stochastic programming methods to potentially improve the quality of the provided solutions. However, when random variables are assumed to be independent, as in most of the current literature on vehicle routing problems (VRP), some of this information is lost. In this talk, we study an extension of the VRP in which the travel times are stochastic and correlated. Routes with high travel time variability are penalized through a mean-variance approach which requires the introduction of a quadratic component into the model. We propose two alternative formulations and develop a Branch-cut-and-price algorithm for both formulations. According to the formulation at hand, the quadratic component is dealt with either in the master problem of the column generation or in the subproblem. Preliminary computational results indicate that our algorithms reasonably efficient and that density of the covariance matrix impacts differently the performance of the two algorithms.

■ HB-08
Thursday, 10:30-12:00 - 205A

Data science and analytics 3

Stream: Data science and analytics (contributed)
Contributed session
Chair: *Sara Tagarian*

1 - Selection of appropriate forecasting model
Ekrem TaÇyildiz, Banu Guner

Using of accurate and reliable forecast in decision making processes is very important. The use of appropriate forecasting methods plays a key role in making accurate and reliable forecasting. In this study, some forecasting models have been applied to historical data of different sectors. The study also includes the methodologies of Chen's work (1996) ,Chen's work (2002) and Rolling GM (1,1) models. Chen's work (1996), Chen's work (2002) models are Fuzzy Time Series Methods. Rolling-GM (1,1) model is a gray prediction method. As a result of the study, Chen's work (2002) model yielded smaller percentages of mean error forecast than the other methods. The forecasting accuracy of the Chen's work (2002)method is better than that of the other used methods.

2 - The case for inliers
Jeffry Savitz

Inliers are subsamples of random samples that can be used in place of random samples to predict population parameters like averages and percentages with the same precision but far fewer data points. Thus, Inliers could be used to reduce costs in survey research for sample acquisition, interviewing and respondent incentives. An empirical study was conducted among over 700 consumers using a national random sample from an online panel in the U.S. Consumers were asked to rate 30 popular brands on a 5-point scale. Average ratings were computed. Inliers were respondents whose ratings were, on average, closer to the average ratings than the average respondent. Inliers predicted the average ratings of all brands with an average absolute deviation of only 2.3%. Moreover, with 2/3 the variance only 2/3 as many of them are needed and at 2/3 the cost. Virtually no significant demographic or psychographic difference surfaced between the two samples. As such, there is no way to target and purchase Inliers and reap the savings. However, using sample from the 28 most highly Inlier dense PRIZM clusters (HIDCs), almost no significant differences surfaced in average brand ratings or demographics. An internal validity check used 1/2 the brands to develop the HIDCs. When applied to the other 1/2 again virtually no significant differences appeared in average ratings between the HIDCs and full random samples. Cost savings could be as much as $1B annually in the U.S. according to CASRO.

3 - The econometric and time series analysis of price dynamics of new and remanufactured products
Supanan Phantratanamongkol, Gu Pang

The ability to understand and forecast price patterns are crucial to Original Equipment Manufacturers (OEMs) especially in the consumer electronics industry due to the products' short life cycle and fierce competitions to maximise profits. Nevertheless, the presence of secondary market and independent sellers together with remanufactured counterparts toughen the predictability of sales. In this paper, we intend to study the price dynamics of products over their life cycles and identify the most suitable method in predicting the price behaviours. We collect transactional data of new and remanufactured smartphones from eBay over a period of one year. The analysis is carried by using econometric models. Our results provide both OEMs and remanufacturers a better understanding of the price dynamics of new and remanufactured products at different life cycle stages so that they can make informed decisions on price setting to capitalise profits.

4 - Developed algorithm for maximum patterns in logical analysis of data
Sara Tagarian, Soumaya Yacout, Hany Osman

Data is the heart of any industry or organization. By increasing the amount and variety of data, the use of facultative traditional methods, were abolished and the importance of providing efficient and fruitful methods to analyze the data is growing. Data classification is one of the ways to fulfill this need of data analysis. Logical Analysis of Data is a methodology to analyze the data. This methodology, the combination of optimization, combinatorics and Boolean logic, is applicable for classification problems. Its aim is to discover hidden logical patterns that differentiate observations pertaining to one class from all of the other observations. Patterns are the key building blocks in LAD. Choosing a set of patterns, capable of classifying observations correctly is the essential goal of LAD. Accuracy represents how successfully this goal is met. In this talk, one specific kind of pattern, called maximum α-pattern, is considered. This pattern helps to build highly accurate LAD classification models. In this paper a computationally efficient and accurate meta-heuristic algorithm based on the Simulated Annealing approach to generate maximum α-patterns is presented. The results of the statistical Friedman test show that the developed algorithm has the best performance in terms of computational time. In terms of accuracy, it is competitive to other methods with, statistically speaking, high levels of confidence.

■ HB-09

Thursday, 10:30-12:00 - 205B

Distribution problems

Stream: Discrete optimization in logistics and transportation
Invited session
Chair: *Jean-François Côté*
Chair: *Manuel Iori*

1 - Optimizing less than truckload distribution through a virtual hub
Thomas Chabot, Florence Bouchard, Ariane Legault Michaud, Jacques Renaud, Leandro Coelho

Less than truckload shipments (LTL) is one of the most popular types of road-base transportation. When we look further on LTL's pricing grids, we can observe that there are no financial benefits for expeditors to manage and synchronize their expeditions, and this leads to large economic and environmental losses. This paper has been motivated by a collaboration with Québec-based companies. In order to help them improve their financial performance and sustainable growth regarding the distribution of their products, we propose, through a virtual hub, to develop partnerships with other companies who share common client locations. Depending on the main concern, we developed three models. The first focuses on shipping and delay costs. The second focuses on the distance traveled and delay costs. The last one focuses on shipping costs, delay costs and distance traveled. The results from these multi-period routing/distribution models demonstrate that collaboration can lead to significant costs and distance savings.

2 - Modeling and solution approaches for the stochastic two-echelon distribution network design problem
Imen Ben Mohamed, François Vanderbeck, Walid Klibi

In this work, we investigate the design of two-echelon distribution networks where product flows towards end-customers must be directed from an upper layer of platforms to Distribution Centers (DCs) before being routed from DCs to customer's base. This problem involves strategic decisions on the location of a set of intermediate DCs over time, the allocation of the capacity level of these DCs for each planning period, and the two-echelon transportation schema of the network. For this design problem under uncertainty, a multi-period planning horizon is considered where demand varies dynamically from one planning period to the subsequent one. Thus, the design of the two-echelon distribution network under uncertain customers' demand gives rise to a complex multi-stage decisional problem. Using a rolling horizon approach and the partition of the planning horizon into a set of design cycles, we formulated the problem as a multi-cycle two-stage stochastic program with recourse. To solve the obtained model a Benders decomposition is developed and coupled with the sample average approximation method. Extensive numerical tests are conducted to validate the modeling and solution approaches proposed for this design problem.

3 - A real-world multi-period routing problem for pharmaceutical distribution
Raphael Kramer, Jean-François Cordeau, Manuel Iori

We present the results of a study that we conducted on a real-world multi-period multi-vehicle distribution problem. In this particular problem, customers have demands on different days of a week that must be supplied by a heterogeneous fleet of vehicles departing from multiple depots. In addition, customers and depots have time window constraints, routes should not exceed a given duration, and incompatibilities between customers and vehicles are given. In order to assist the logistic distribution, intermediate depots may be used to temporally store the products to be delivered later by other vehicles at the appropriate time. Two variants of the problem are investigated: one in which the intermediate depots are given as an input, and another in which the opening of the depots is a decision to be taken. The problem derives from a public call to logistic providers for organizing the delivery of medicines to health care establishments and hospitals in the Tuscany region (Italy). The call furnishes data from the last few years of distributions in the region, thus presenting a very interesting study case for optimization. To solve the problem, we propose an Iterated Local Search algorithm whose computation behavior is evaluated by means of a large set of computational experiments, executed both on the real case instances and on new randomly generated instances.

■ HB-10

Thursday, 10:30-12:00 - 205C

Applications in location and transportation

Stream: Location
Invited session
Chair: *Diego Ruiz-Hernandez*

1 - Development of vehicle charging facility location problem based on flow-capturing location-allocation model
Yohei Kakimoto, Hirotaka Takahashi, Yoichi Shimakawa, Hiroyuki Goto

In this study, we formulate a location problem for electric vehicle (EV) charging facilities as a flow-capturing location-allocation problem and try to locate these facilities relative to the road network using geographic information systems. The demand in the flow-capturing location-allocation problem is the traffic flow on the road network. More than two facilities located on a single route between an origin and a destination consume the same traffic demand for the route. This is called "cannibalization" and must be considered when selecting charging facility locations. We develop the model to fit EV charging facility needs based on the flow-capturing location-allocation problem. This location problem has issues unique to EV charging facilities. The EV running distance is much shorter than that of gasoline-powered vehicles. It also takes a much longer time to charge a battery than to simply refuel a vehicle. In formulating this problem, we have tried to integrate these features of EV charging facilities into the model. We solved the location problem numerically using relaxed linear programing. The effects of our modifications and the limitations of the computation are shown as results.

2 - Biorefinery location and green perspectives: A practical approach
Javier Faulin, Adrian Serrano, Javier Belloso

The instability of oil production and their prices, along with the environmental nuisance associated to fossil fuels, are making biofuels an emerging energy source worldwide. Biofuels are derived from biomass in complex facilities called biorefinery. Thus, feedstock supply is a critical issue to which the biorefinery management has to cope with. Moreover, the location of the biorefinery would determine the biomass availabilities as well as the operation planning throughout the year. This work proposes a mixed linear integer programming model to locating and defining the supply chain of a biorefinery in Northern Spain. Biomass location, production a seasonality are thoroughly considered resulting in a high detailed problem definition. Finally, several what-if analysis are run showing a huge range of promising results at both strategic and operational levels.

3 - Inducing universal access to privately managed social interest goods via location decisions
Diego Ruiz-Hernandez, Javier Elizalde, Amaya Erro

Even though certain social interest goods, such as health services, may be provided by private firms, the public authority may still be interested in guaranteeing universal access for all its citizens. This is often achieved by enforcing rules that guarantee full provision and adequate prices. Considering that in many cases (e.g. hospitals, schools) the location of facilities is of extreme importance, we use a simple model of spatial monopoly with geographic concentration of demand for analysing the effect on coverage and welfare of two alternative public policies: regulation of facilities' location, and allowance for price discrimination across consumers (associated to the commuting distance). Our theoretical results predict that, with price discrimination, universal access takes place more often and the provider of the service, who extracts the whole consumer surplus, tends to open the facilities in the most populated town of the region. Instead, with a universal price, the service is rather run from neutral locations. Moreover, only when the willingness to pay for the service is high the customers may be able to retain certain surplus. This only happens when the government dictates the place from which the service is run.

■ HB-11

Thursday, 10:30-12:00 - 206A

Network optimization

Stream: Telecommunications and network optimization
Invited session
Chair: S. Raghavan

1 - Clustered intersected TSP approximation algorithms
Michal Stern, Nili Beck, Eyal Knaan

Let G=(V,E) be a complete undirected graph with vertex set V, edge set E and let H = <G,S> be a hypergraph, where S is a set of non-disjoint clusters from V. The clustered traveling salesman problem CTSP is to compute a shortest Hamiltonian path that visits each one of the vertices once, such that the vertices of each cluster are visited consecutively. In this paper we present a 4-approximation algorithm for the general case. We refer to the special case where the clusters of the hypergraph are weakly independent, defined by the property that every cluster is not contained in the union of any two different clusters. For this case we present two 5/3-approximation algorithms, whose complexity depends on the sizes of the clusters' intersections. When the clusters sizes are all bounded by a constant, without any additional constraint on the intersections sizes, we present an optimal polynomial time algorithm.

2 - New path elimination constraints for multi-depot and location-routing problems
Luís Gouveia, Tolga Bektas, Daniel Rebelo dos Santos

This talk describes new directed inequalities, namely multi-cut constraints (MCC), for multi-depot routing problems with a given set of depots, that enforce the requirement that the route of each vehicle starts and ends at the same depot. The MCCs are exponential in size, and are equivalent, to a compact three-index formulation for the problem in terms of the associated linear programming relaxations. The connection between the compact and the exponential formulations implies a polynomial separation procedure based on max-flow/min-cut computations. We also consider location problems where any node in the graph can be used as a depot, in particular the Hamiltonian p-median problem, which consists of finding p mutually disjoint circuits of minimum cost such that each node of the graph is included in one of the p circuits. Recently proposed formulations are based on viewing the problem as resulting from the intersection of two subproblems, one requiring at most p circuits and another at least p circuits. We show that the MCCs, can be tailored for the Hamiltonian p-median problem to prevent solutions with less than p circuits. Computational results for the two variants will be presented at the talk.

3 - Generalizations of the dominating set problem on social networks
S. Raghavan, Rui Zhang

We study two generalizations of the dominating set problem set problem on social networks. The Positive Influence Dominating Set (PIDS) problem is defined as follows. Given a graph G = (V,E), each node i in V has a weight, denoted by b(i), and a neighbor requirement, denoted by g(i). We seek a subset P of V such that a node i not in P is adjacent to at least g(i) members of P and the sum of weights of those nodes in P is minimized. Notice, when g(i)=k for all nodes in the graph we obtain the k-dominating set problem, where k=1 gives the dominating set problem. The PIDS problem is motivated by applications on social networks. Roughly, the notion is that the set of nodes selected in P are able to influence a desirable behavior in the rest of the network. Another variant of the PIDS problem—referred to as the Total PIDS problem—requires that every node in the graph (i.e., including the nodes in P) be adjacent to g(i) nodes in P. We present a dynamic programming approach to solve both the PIDS and the TPIDS problem on trees. We then focus on the polytope of these two problems. In particular, we describe the polytope of both problems when restricted to trees. Interestingly the formulation for trees is also valid on general graphs, and thus provides a strong formulation for these problems on arbitrary graphs. We discuss our computational experience with these formulations.

■ HB-13

Thursday, 10:30-12:00 - 207

Reduction and efficient bounding in conic optimization

Stream: Copositive and conic optimization
Invited session
Chair: Paula Amaral

1 - Completely positive lower bounds for min-max fractional quadratic problems
Paula Amaral, Immanuel Bomze

In this presentation we address min-max problems of fractional quadratic functions over a polytope. The fractional min-max problem occurs, among others in the study of worst-case analysis when different scenarios are under evaluation. Fractional programs are in general non-convex programs and exact methods require the existence of good lower bounds. The merits of copositive and completely positive optimization are recognized in the reformulations of hard optimization problems, such as continuous non convex, mixed integer quadratic, continuous and mixed integer fractional quadratic problems. An important feature of completely positive formulations is that its relaxations give tight lower bounds. In this presentation we present completely positive formulations for min-max fractional quadratic problems and study the quality of the lower bounds obtained using the relaxation of the completely positive cone.

2 - On reduced semidefinite programs for second order moment bounds with applications

Karthik Natarajan, Chung Piaw Teo

We show that the complexity of computing the second order moment bound on the expected optimal value of a mixed integer linear program with a random objective coefficient vector is closely related to the complexity of characterizing the convex hull of the points (1 x)(1 x)' for x in X where X is the feasible region. In fact, we can replace the completely positive programming formulation for the moment bound on X, with an associated semidefinite program, provided we have a linear or a semidefinite representation of this convex hull. As an application of the result, we identify a new polynomial time solvable semidefinite relaxation of the distributionally robust multi-item newsvendor problem by exploiting results from the Boolean quadric polytope.

3 - Dimension reduction for semidefinite programs

Frank Permenter, Pablo Parrilo

We propose a new method for simplifying semidefinite programs (SDP) inspired by symmetry reduction. Specifically, we show if an orthogonal projection satisfies certain invariance conditions, restricting to its range yields an equivalent primal-dual pair over a lower-dimensional symmetric cone—namely, the cone-of-squares of a Jordan subalgebra of symmetric matrices. We then give a simple algorithm for minimizing the rank of this projection and hence the dimension of this cone. We demonstrate effectiveness on SDP relaxations of polynomial optimization problems.

■ HB-14

Thursday, 10:30-12:00 - 305

Sharing and collaboration for sustainable transportation

Stream: Sustainable logistics
Invited session
Chair: *Stefan Voss*
Chair: *Frederik Schulte*

1 - Modeling mobility as a service in a corporate setting

Miriam Enzi, Benjamin Biesinger, Sebastian Knopp, Sophie Parragh, Matthias Prandtstetter

This work targets future mobility concepts by providing mobility as a service and considers corresponding optimization problems arising in the area of fleet management, vehicle routing, and vehicle assignment. It is part of a research project which intends to introduce novel (company) mobility services integrating private and business trips. The project is linked with the idea of "future mobility" where mobility is seen as a shared resource that can be consumed instead of a personal property. In a corporate context the focus associated with these ideas is on shifting from company cars owned by a single employee to a system where staff cars, including battery electric vehicles, are provided "on demand" and other options such as public transportation, car sharing systems, or bike-sharing are used as well. The overall goal is to enable alternative mobility possibilities in order to achieve an efficient utilization of the company fleet and assure seamless mobility. The underlying problem is modeled as a mixed integer linear program so as to optimize the vehicle-to-tour assignment and the fleet size and mix on a rolling horizon basis. Battery load management and the necessary charging infrastructure for electric vehicles are associated topics of interest. We will compare different mixed integer linear programs and we will present first results illustrating the impact of multi-modal mobility and the associated fleet management on several factors such as cost and CO2 emissions.

2 - Colaborative transportation under Cournot competition

Franco Basso, Leonardo Basso, Mikael Rönnqvist, Andrés Weintraub

Horizontal collaboration in logistics is defined as the coordination of some operational activities among competitors firms. Some successful cases in transportation have been reported in literature, but have occurred over limited ranges of time. Until now, the OR models used to study the horizontal collaboration in transportation have not included competition between firms: contracts are signed, and both quantities and prices are fixed. Without competition, agreements always save on costs and it is then a matter of allocating costs savings wisely. In our model we consider a coalition formation game but prior to market equilibrium; that is, we propose a collaborative model in which, after the agreements are signed, the different firms and coalitions compete in multiple markets in Cournot fashion. When this happens, the formation of one set of coalitions affect prices and production levels of all other competitors, something that did not occur in the previous literature. Possible partnership among these firms are allowed and studied. One main result is that, as opposed to what has been found in the literature to date, forming coalitions that are beneficial to firms in the agreement is actually quite hard, which would explain why collaboration has not been observed as much as expected. We propose two models to respond the question of which coalitions will be formed in this setting, including at times the restriction that the agreement should be cleared by antitrust authorities.

3 - Robust ride-sharing with client clustering under travel time uncertainty

Sunghoon Chung

Ride-sharing has attracted researchers' attention thanks to its positive effects such as reducing air pollution and traffic congestion. In this paper, we consider a dynamic ride-sharing problem in which information on riders (clients) and volunteer drivers (servers) is updated daily and drivers' routes need to be calculated quickly. We assume travel times between pick-up locations are subject to uncertainty and propose a robust optimization approach to handle it properly. To achieve the computational tractability, we employ the insertion algorithm in conjunction with Tabu search algorithm to find heuristic solutions. In addition, we propose a cluster-first-route-second approach for computational tractability. In particular, the greedy algorithm and k-means algorithm are used to group the client nodes and their respective results along with non-clustering case are compared.

4 - Cooperation to reduce emissions in road transport: Efficient core and shapley value allocations for a cooperative truck scheduling problem

Frederik Schulte, Eduardo Lalla-Ruiz, Silvia Schwarze, Stefan Voss, Rosa G. González-Ramírez

Cooperation is widely seen as a major pathway to more efficient and sustainable resource utilization. Conventional approaches for individual profit maximization in transportation often cause significant pollution that may be reduced when effective cooperation among individuals is established. Studies in cooperative game theory and sustainable development have demonstrated the potential of cooperation approaches for environmental sustainability. Moreover, the development in mobile technology and information systems has clearly simplified coordination among individuals. Nevertheless, models for realistic transportation problems often assume cooperation without explicitly considering the rational decisions of individual participants. We present a mathematical model for a cooperative truck scheduling problem aiming to reduce port emissions and apply concepts of cooperative game theory to grant effective cooperation. In order to solve realistic problem instances, we develop an iterative Shapley value algorithm and a row generation based core algorithm. The results show that we are able to solve problem instances of realistic size to effectively reduce emissions by enabling and incentivizing cooperation.

■ HB-15

Thursday, 10:30-12:00 - 307A

Dynamics, games and optimization

Stream: Applications of dynamical models
Invited session
Chair: *Damián Emilio Gibaja Romero*
Chair: *Montserrat Pons*

1 - A colourful generalization for the poison Game
Damián Emilio Gibaja Romero

The "Poison Game" is a two player combinatorial game, on a finite directed graph, where players 'a' and 'b' sequentially choose a successor of the vertex previously chosen by the other player. When player 'a' moves first, player 'b' poisons each vertex that he chooses, i.e. 'a' cannot choose a vertex previously chosen by 'b'. Duchet and Mayniel (1993) show that 'a', the player who moves first, wins the game if and only if the directed graph has a kernel, which is a set of independent and absorbent vertices. This paper presents a generalization for the poison game considering n pairs of players that play simultaneously the poison game on a finite n-coloured directed graph, and each pair is associated to a color. That is to say, there are n players of type A, and n players of type B. As before, type A players move first and cannot choose a vertex previously chosen by type B players; agents in a pair only can move following a path of their associated color. In this framework, the concept of kernel by monochromatic paths is the natural generalization for the kernel concept. We show that the n-coloured digraph has a kernel by monochromatic paths when all type A players win their corresponding poison game, but the converse is not true. That is to say, a kernel by monochromatic paths does not guarantee that type A players win. Thus, the main result of Duchet and Mayniel cannot be generalized in this framework.

2 - Bregman learning dynamics for robust stochastic games
Hamidou Tembine

In big data machine learning, a discriminative task seeks to classify some input, and a generative task seeks to create a model that can generate data that looks like the training data. The interaction between these networks can be seen as a robust game in deep generative adversarial networks. In this paper we develop adversarial learning algorithms for robust games. Firstly, the problem of minimizing an objective function subject to the dissimilarity between the generator and the discriminator distribution is introduced using a divergence function. The static robust optimization problem which is an infinite dimensional problem is transformed into a finite dimensional problem using Legendre-Fenchel duality theory. Secondly, the existence of solution is discussed in both zero-sum and non-zero-sum robust games. Thirdly, a general Bregman-based learning algorithm is proposed to find a solution. The algorithm is shown to have a convergence time that is doubly logarithmic in the precision of the equilibrium value. Fourthly, the methodology is extended to a dynamic situation in which an object can be deformed/corrupted/falsified by the discriminator and a connection with robust mean-field-type games is established. Lastly, the existence of robust mean-field-type equilibrium is established under suitable conditions.

3 - COA modeling based on stochastic games
Chao Chen, Changjun Fan

The development of Course of Action (COA) is a key step of military planning. In most existing literature on COA development, they just take unilateral actions of friendly force into account. Considering the uncertainty of war, we propose models based on stochastic games. The existence of equilibrium was analyzed and the resolving methods were given. In the end, numerical examples were presented to illustrate the models and solution.

4 - Intertemporal consumption bundling with sharing markets
Maryam Razeghian, Thomas Weber

Empirical evidence suggests that consumers' propensity towards sharing varies with culture and the individuals' socio-demographic characteristics. In an economy with overlapping generations of heterogeneous consumers with different needs for a product, we study optimal dynamic selling by a durable-goods monopolist in equilibrium. Feasible dynamic pricing strategies include second-degree price discrimination offering intertemporal consumption bundles in the form of rental and/or purchase options. We find that as the population's sharing propensity increases, possibly due to a cultural shift from ownership to access-based consumption, the durable-goods monopolist's optimal strategy shifts from unbundling (offering exclusively rentals), via mixed bundling (offering the options of rental and purchase side-by-side), to pure bundling (purchase only). We find that an increase in sharing propensity has an ambiguous effect on the firm's profit. Cultural shifts from low to high sharing propensity may be delayed by a firm's attempts to artificially disable sharing markets by offering overly low rental rates. However, beyond a certain threshold of sharing propensity, the firm actually prefers a faster cultural transition to an access-based economy. The underlying reason is that the asset base of a sharing economy ultimately depends on the firm's output, so that a portion of the available surplus can be captured by the durable-goods monopolist.

■ HB-16

Thursday, 10:30-12:00 - 308A

Cooperation and competition in supply chains

Stream: Game theory and operations management
Invited session
Chair: *Qiong Wang*

1 - A non-cooperative approach to cost allocation in joint replenishment
Xuan Wang, Simai He, Jay Sethuraman, Jiawei Zhang

We consider the infinite-horizon multiple retailer joint replenishment problem with first order interaction. In this model, the joint setup cost incurred by a group of retailers placing an order simultaneously consists of a group-independent major setup cost and retailer-specific minor setup costs. The goal is to determine an inventory replenishment policy that minimizes the long-run average system-wide cost. We consider the allocation rule in which the major setup cost is split equally among the retailers who place an order together, and each retailer pays his own holding and minor setup costs. Given the preannounced allocation rule, each retailer determines his replenishment policy to minimize his own cost anticipating the other retailers' strategy. We show that a payoff dominant Nash equilibrium exists and quantify the efficiency loss of the non-cooperative outcome relative to the social optimum.

2 - Simultaneous penalization and subsidization for stabilizing grand coalitions in unbalanced cooperative games
Lindong Liu, Xiangtong Qi, Zhou Xu

In this work we propose a new instrument for stabilizing the grand coalition of a cooperative game with an empty core. The new instrument, referred to as simultaneous penalization and subsidization, integrates two unconnected concepts in the literature. Its basic idea is to charge a penalty from players who may deviate from the grand coalition, and at the same time provide a certain subsidy to the grand coalition. To formalize the idea, we establish a model based on a penalty-subsidy function, which allows a decision maker to quantify the tradeoff between penalty and subsidy levels. By studying function, we analytically derive certain properties regarding the tradeoff, which provides useful insights to the decision maker. To implement the new instrument, we design two algorithms that can be used to construct the function and its approximation on the entire effective domain. Both algorithms rely on solving the value of minimum subsidy for any given penalty level, for which we propose two effective solution approaches. We apply our new model, algorithms, and solution approaches to a class of parallel machine scheduling games, which not only demonstrates the wide applicability of our new instrument, but also reveals some interesting properties of these games.

3 - Cooperation and contract design in project management with subcontracting

Xiao-qiang Cai, Nicholas Hall, Feng Zhang

We study a project management problem in which the prime contractor outsources tasks to a set of subcontractors, who perform them using their own resources. Achieving an optimal project schedule requires: (i) coordination among the subcontractors; and (ii) contract design by the prime contractor, to incentivize the subcontractors to perform their tasks appropriately. We model the coordination problem of the subcontractors as a cooperative game. We show that this game is balanced, hence the subcontractors cooperate if an appropriate profit sharing scheme is adopted. We derive such a scheme by solving a linear program. We consider the contract design problem of the prime contractor who customizes incentives for each subcontractor. We develop efficient algorithms to compute the optimal contract parameters. We conduct computational experiments to analyze the sensitivity of project performance to parameter estimation in contract design. We find that the pooling effect of subcontractors' cooperation mitigates the negative impact of poor estimates.

4 - Population monotonicity in newsvendor games

Qiong Wang, Xin Chen, Xiangyu Gao, Zhenyu Hu

A newsvendor game studies whether players can collaborate on inventory pooling, where the cost allocationis usually analyzed by the notion of core in cooperative game theory. It is known that the core of thenewsvendor game is non-empty and one can use duality theory in stochastic programming to constructan allocation belonging to the core, which we refer to as the dual-based allocation scheme. However, anallocation that lies in the core does not necessarily guarantee the unhindered formation of a coalition, as someexisting members' allocated costs may increase when new members are added in the process. In this work, we use the concept of population monotonic allocation scheme (PMAS), which requires the cost allocatedto every member of a coalition to decrease as the coalition grows, to study allocation rules in a growingpopulation. We focus on the dual-based allocation scheme and identify conditions under which it is a PMAS. Specifically, we show that if the demands faced by the newsvendors are independent and log-concave, thenthe dual-based allocation scheme is a PMAS. When the demands are dependent, the dual-based allocationscheme is a PMAS if the growth of the coalition does not increase the dependence structure, measured bythe copula, between each player and the coalition. We further demonstrate our conditions for populationmonotonicity for a few special cases with simple dependence structure.

■ HB-17

Thursday, 10:30-12:00 - 309A

Nonlinear optimization with uncertainties 2

Stream: Nonlinear optimization with uncertainties
Invited session
Chair: *Angelia Nedich*
Chair: *Wei Shi*

1 - Distributed non-convex optimization

Behrouz Touri, Tatiana Tatarenko

In this talk, we discuss distributed optimization over time-varying networks with non-convex objective function. We show that under proper connectivity assumption of the time-varying network, the push-sum distributed optimization method converges to the set of critical points under mild conditions on the objective function. We show that under additional assumptions, the updates converge to the set of local-minima of the underlying objective function.

2 - DeFW: Projection-free multi-agent optimization

Hoi To Wai, Jean Lafond, Anna Scaglione, Eric Moulines

This work proposes the first projection free algorithm for consensus based multi agent optimization. We consider a setting when the objective is to minimize a composite smooth function subject to a convex constraint that is compact. To handle the high dimensional constraint, we develop a decentralized Frank Wolfe (DeFW) algorithm for it that is projection free. The latter is a special case of a perturbed Frank Wolfe algorithm. We analyze its convergence rates in the case of convex and non convex objectives, respectively. Importantly, the DeFW algorithm applies a dynamic network consensus technique such that the perturbed iterates track their unperturbed counterparts with increasing accuracies over the iteration number, while requiring a constant number of communication rounds per iteration. This also allows us to perform asynchronous distributed optimization in a projection free manner. Numerical experiments on low rank+sparse matrix completion are shown to support our results.

3 - Balancing computation and communication in distributed optimization

Albert Berahas, Ermin Wei, Raghu Bollapragada, Nitish Keskar

In this talk we present an algorithmic framework for balancing computation and communication in distributed optimization. In contrast to algorithms such as DGD and EXTRA, which employ alternating optimization and consensus steps, we propose adaptively increasing the number of communication steps. We apply this framework to first-order methods, such as DGD, and show that they compare favorably relative to their base algorithms. Finally, we describe current efforts on various algorithms, including primal-dual and second-order algorithms.

4 - A class of decentralized resource allocation algorithms and its connection to consensus optimization

Wei Shi, Angelia Nedich, Alex Olshevsky

In this talk, we discuss the resolution to a convex resource allocation problem defined over a bidirectionally connected multi-agent network, where the agents' objectives are decoupled while the resource constraints are coupled. The agents want to collaboratively determine a solution to the overall optimization problem while each agent only communicates with its neighbors. We first study the connection between the decentralized resource allocation problem and the decentralized consensus optimization problem. Then based on a class of algorithms for solving consensus optimization problems, we propose a novel class of decentralized schemes for solving resource allocation problems in a distributed manner. Specifically, we first propose an algorithm for solving the resource allocation problem with an o(1/k) convergence rate guarantee when the agents' objective functions are generally convex (could be nondifferentiable) and per agent local convex constraints are allowed; We then propose a gradient-based algorithm for solving the resource allocation problem when per agent local constraints are absent and show that such scheme can achieve geometric rate when the objective functions are strongly convex and have Lipschitz continuous gradients. We have also provided scalability/network dependency analysis. Numerical experiments have demonstrated the viability and performance of all the proposed algorithms.

■ HB-18

Thursday, 10:30-12:00 - 2101

Numerical methods for multiobjective optimization problems

Stream: Multiobjective optimization
Invited session
Chair: *Andreas Löhne*
Chair: *Matthias Ehrgott*

1 - Global optimization techniques for robust multiobjective optimization
Gabriele Eichfelder, Julia Niebling, Stefan Rocktäschel

A well-known deterministic method in scalar-valued global optimization is the alpha Branch and Bound (alphaBB) method which uses convex underestimators of the objective function and a partition of the search domain. We use the technique of convex underestimators for deriving a method to solve multiobjective optimization problems globally. Moreover, we apply these techniques also for computing a covering of the optimal solutions of a robust multiobjective optimization problem. There, decision uncertainty is taken into account by considering to each variable all possible realizations and the correspondent objective function values. By choosing a robust approach this leads to a special set optimization problem.

2 - The boxed line algorithm for mixed integer biobjective optimization
Tyler Perini, Natashia Boland, Diego Pecin, Martin Savelsbergh

Recent years have seen a surge of new algorithms for solving multi-objective integer programs, especially for the pure integer case. The presence of continuous variables presents significant challenges to discovery of the nondominated frontier, and development of algorithms for the mixed integer case have lagged. Here, we present a new algorithm for mixed integer problems with two objectives, which generalizes the Balanced Box Method (BBM) for pure integer programs. It retains the benefits of BBM in its organization of the search, but splits far fewer line segments in the frontier than its cousin, the Triangle-Splitting method, does. The computational performance of the Boxed Line Algorithm is compared with that of existing methods on benchmark problems, in terms of its overall run-time, and its ability to approximate the frontier if terminated early.

3 - Primal and dual algorithms for the optimisation of a linear function over the non-dominated set of a multi-objective optimisation problem
Matthias Ehrgott, Zhengliang Liu

Optimisation over the non-dominated set of a multi-objective optimisation problem is a mathematical model for the problem of selecting a most preferred solution from the efficient set. In this paper we consider the case of optimising a linear objective function over the non-dominated set of a convex multi-objective optimisation problem. We present both primal and dual algorithms for this task. The algorithms are based on recent algorithms for solving convex multi-objective optimisation problems in objective space with suitable modifications to exploit the special structure of the problem. We first present the algorithm for the case that the underlying problem is a multi-objective linear programme. We then extend them to be able to solve problems with an underlying convex multi-objective optimisation problem. We compare the new algorithms with several state of the art algorithms from the literature on a set of randomly generated instances to demonstrate that they are considerably faster than the competitors.

■ HB-19

Thursday, 10:30-12:00 - 2102AB

Advances in robust optimization and control

Stream: Robust optimization
Invited session
Chair: *Angelos Georghiou*

1 - Scenario reduction revisited: Fundamental limits and guarantees
Napat Rujeerapaiboon, Kilian Schindler, Daniel Kuhn, Wolfram Wiesemann

The goal of scenario reduction is to approximate a given discrete distribution with another discrete distribution that has fewer atoms. We distinguish continuous scenario reduction, where the new atoms may be chosen freely, and discrete scenario reduction, where the new atoms must be chosen from among the existing ones. Using the Wasserstein distance as measure of proximity between distributions, we identify those n-point distributions on the unit ball that are least susceptible to scenario reduction, i.e., that have maximum Wasserstein distance to their closest m-point distributions for some prescribed $m < n$. We also provide sharp bounds on the added benefit of continuous over discrete scenario reduction. Finally, to our best knowledge, we propose the first polynomial-time constant-factor approximations for both discrete and continuous scenario reduction as well as the first exact exponential-time algorithms for continuous scenario reduction.

2 - Robust control with adjustable uncertainty sets: Providing frequency reserves to the power grid via demand response
Angelos Georghiou

Given a fixed uncertainty set, robust control finds a policy that minimizes a given cost while satisfying the system's constraints for all uncertainty realizations. In this work, we extend the robust control setup by allowing both the policies and the uncertainty sets to be decision-dependent, which we refer to as adjustable uncertainty sets. By restricting the set of admissible policies, we can cast the problem as a tractable convex optimization problem. We showcase the effectiveness of our approach on a demand response problem, providing frequency reserves to the power grid.

3 - Two-stage robust linear programming over Wasserstein balls
Grani A. Hanasusanto, Daniel Kuhn

Adaptive robust optimization problems are usually solved approximately by restricting the adaptive decisions to simple parametric decision rules. However, the corresponding approximations error can be substantial. In this talk we show that two-stage robust and distributionally robust linear programs can often be reformulated exactly as conic programs that scale polynomially with the problem dimensions. Specifically, when the ambiguity set constitutes a 2-Wasserstein ball centered at a discrete distribution, then the robust linear program is equivalent to a copositive program (if the problem has complete recourse) or can be approximated arbitrarily closely by a sequence of copositive programs (if the problem has sufficiently expensive recourse). These results directly extend to the distributionally robust setting and motivate strong tractable approximations of two-stage problems based on semidefinite approximations of the copositive cone.

4 - Robust dual dynamic programming
Angelos Tsoukalas, Angelos Georghiou, Wolfram Wiesemann

We propose a robust dual dynamic programming (RDDP) scheme for multi-stage robust optimization problems. The RDDP scheme takes advantage of the decomposable nature of these problems by bounding the costs arising in the future stages through inner and outer approximations. Similarly to the Stochastic Dual Dynamic Programming algorithm (SSDP) for stochastic programming problems, our algorithm employs forward and backward passes to refine the approximations. In contrast to SDDP, which relies on randomisation in the forward pass to determine the points of refinement, we refine deterministically using as a device our inner approximations. Our algorithm converges deterministically, and for problems with uncertain technology matrices and/or constraint right- hand sides, in finite time. If also the objective function and/or the recourse matrices are uncertain, our method converges asymptotically to an optimal solution. We present numerical results illustrating the good practical performance of our algorithm.

■ HB-20

Thursday, 10:30-12:00 - 2103

Dynamical models in sustainable development 1

Stream: Dynamical models in sustainable development
Invited session
Chair: Emilio Galdeano-Gómez

1 - Production phases and market for timber gridshell structures
Marzieh Ghiyasinasab, Nadia Lehoux, Sylvain Ménard

The aim of this research is to investigate timber gridshell structure and its samples to identify its global production process as well as the stakeholders involved in the samples studied. Gridshell is not widely acknowledged as a timber solution and there is a lack of academic research focusing on the potential markets and the production stages behind it. This research attempts to develop these points of view and facilitate production management during construction phases. A literature review based on both academic papers and grey literature is conducted to gather information about timber gridshells. The samples are categorized based on their size and level of complexity as small, medium, and large gridshells. Moreover, production phases of a real sample are observed and analyzed. Production phases and players involved in the design and the construction of these structures is identified. The result shows that the gridshell is used in the non-construction industry as twenty samples are identified. The global production process and the role of stakeholders are identified for each category. Furthermore, motivations and barriers to use gridshells in construction are determined. Innovative structures that encourage the use of wood in construction are important in the development of sustainable solutions. The results of this paper lead to make gridshells increasingly recognized for both the clients and those who are interested in exploiting this structure.

2 - Predicting short-term traffic congestion on urban motorway networks
Taiwo Adetiloye, Anjali Awasthi

The trends show that improvements being made to advance traffic management system come in various forms from finding the type of traffic recording equipment, the techniques of data collection, cleaning data, accurate and reliable analytic methods to adequate means of simulating traffic scenarios before putting them to actual use. We investigate data mining based models for prediction of short-term traffic congestion on urban motorway networks. Our initial step involves analysis of different data sources: Global Positioning System (GPS), sensors, twitter, and computer-based model. Sentiment analysis using Part of Speech (POS) tag for traffic congestion is presented. Also, we present a computer-based model for the analysis of the traffic vehicle behaviors in congested traffic during rush hour period, at intersections and in the presence of an emergency vehicle. In addition, we consider data fusion estimation techniques based on a distributed architecture and, in particular, with regards to using Extended Kalman Filter(EKF) to ensure lower error probability and to obtain a linear optimal solution. Subsequently, our preliminary results using back propagation neural network, neuro-fuzzy, deep belief network and random forests on GPS and sensor homogeneous fused data were improved under a distributed, two-phase mode, architecture. The final step of the error reduction for the fused data is then performed by applying the recursive repeat and correct operations of the EKF.

3 - Assessing eco-efficiency and its determinants of horticultural farming in southeast spain
Emilio Galdeano-Gómez, Angeles Godoy-Durán, Juan Carlos Perez Mesa, Laura Piedra-Muñoz, Cynthia Giagnocavo

Eco-efficiency is currently receiving ever more interest as an indicator of sustainability, as it links environmental and economic performance in productive activities. In agriculture these indicators and their determiners prove relevant due to the close ties in this activity between the use of often limited natural resources and the provision of basic goods for society. The present paper analyzes eco-efficiency at micro-level focusing on family farms as the principal decision-making units (DMUs) of horticulture in southeast Spain. To this end, Data Envelopment Analysis (DEA) framework is applied, computing several combinations of environmental pressures (water usage, phytosanitary contamination, waste management, etc.) and economic value added. In a second stage we analyze the influence of family farms' socio-economic and environmental features on eco-efficiency indicators, as endogenous variables, by using a Tobit model. The results show major inefficiency in aspects such as waste management, among others, while there is relatively minor inefficiency in water usage or nitrogen balance. On the other hand, features such as product specialization, adoption of quality certifications and belonging to a cooperative all have a positive influence on eco-efficiency. These results are deemed to be of interest for agrifood systems structured on small-scale producers, and they may prove useful to policy-makers as regards managing public environmental programs in agriculture.

■ HB-21

Thursday, 10:30-12:00 - 2104A

Cutting and Packing 3

Stream: Cutting and packing
Invited session
Chair: Joao Pedro Pedroso

1 - Integer programming models for the quasi-polyomino strip packing problem
Marcos O. Rodrigues, Franklina Toledo

A polyomino is a set of unit squares connected by joining one of their edges. A quasi-polyomino is a polyomino generalization, since it is a subset of not necessarily connected squares obtained from an equidistant raster grid. Quasi-polyomino cutting and packing problems have many real applications, e.g., leather cutting, sheet metal stamping, design of printed circuit boards and layout of magazines and newspapers. In this paper, we study the quasi-polyomino strip packing problem. We propose two integer programming models for the problem and evaluate them using state-of-the-art solvers. We evaluate the models using instances taken from the literature and both models obtained good results, solving to optimality instances with up to 320 items (20 distinct items) on a strip of dimensions 44x50.

2 - A BRKGA-based matheuristic for the irregular strip packing problem
Larissa Oliveira, Franklina Toledo, Maria Antónia Carravilla, José Fernando Oliveira

The cutting and packing problem consists in finding a layout for small pieces that must be cut from a larger object, while minimizing the raw-material waste. Among the many variants of this problem, we focus on the irregular strip packing problem, whose main characteristic, and obstacle, is the irregular shape of the small pieces. In the irregular strip packing problem the large object has its height fixed and the goal is to minimize the used length. In this study, we propose a matheuristic based on the biased random-key genetic algorithm (BRKGA) where the decoder is a linear programming model that minimizes the conflicts of positioning the pieces over the object. The non-overlapping constraints are written based on the edges of the nofit polygons (NFP) of the pairs of pieces. Each solution in the BRKGA is encoded as a vector of n random keys, where n is the total number of NFP and the keys encode which edges of the NFP will be used to guarantee the no overlapping between the pieces.

3 - Exact methods for recursive circle packing
Stephen Maher, Ambros Gleixner, Benjamin Müller, Joao Pedro Pedroso

Packing rings into a minimum number of rectangles is an optimization problem that appears naturally in the logistics operations of the tube industry. Considering each rectangle as a transportation container, minimal transportation costs are given by recursively packing rings into the smallest number of rectangles. No exact solution methods exist for the recursive circle packing problem (RCPP)—a more difficult variant of the circle packing problem—with the best heuristic algorithms only able to find solutions for small instances. A cutting stock formulation of the RCPP is described that reduces the difficulty of the problem that arises due to the recursive nature. An exact column generation algorithm is developed by applying a Dantzig-Wolfe reformulation to the cutting stock formulation of the RCPP. The exact column generation algorithm is demonstrated to outperform previous heuristic approches by providing improved upper bound solutions and strong lower bounds for a large collection of test instances.

■ HB-22

Thursday, 10:30-12:00 - 2104B

Paths and sequences

Stream: Discrete optimization, mixed integer programming (contributed)
Contributed session
Chair: Rosa Medina

1 - Enumeration of all the longest paths between two nodes using a small-m method
Hiroyuki Goto, Yoichi Shimakawa, Masashi Miyagawa

Focusing on weighted directed graphs without a positive cycle, we develop a method for enumerating all the longest paths between two arbitrary nodes. The main objective is not to find a single path but to detect all the longest paths with the same maximum cumulative weight. We formulate the framework as a constraint satisfaction problem in MILP (Mixed-Integer Linear Programming), for which the solution can be obtained using a general-purpose MILP solver. We do not need to set an objective function. The framework is thus beneficial since it is incorporable into other optimization frameworks. We shall call the key technique small-m method, which is named in contrast to the big-M technique occasionally used in solving MILP problems. We are aiming to apply the framework to scheduling problems such as PERT (Performance Evaluation and Review Technique) and CCPM (Critical Chain Project Management), by which all the critical paths or critical chains can be detected. With a slight modification, the developed framework can be changed to a solution method for enumerating all the shortest paths.

2 - Adding edges with short lengths between one node and every other node of the same depth in a complete K-ary tree
Kiyoshi Sawada

A rooted tree can express a pyramid organization structure with relations between each superior and his subordinates. Then nodes and edges in the rooted tree correspond to members and relations between members in the organization respectively and the path between a pair of nodes in the rooted tree is equivalent to the route of communication of information between a pair of members in the organization. Furthermore, adding edges to the rooted tree is equivalent to forming additional relations to the organization. We have proposed a model of adding edges between one node and every other node of the same depth N in a complete K-ary tree of height H for the purpose of revealing optimal additional relations. The optimal depth N* is obtained by maximizing the total shortening distance which is the sum of shortened lengths of shortest paths between every pair of all nodes by adding edges. This model is expressed as all edges have the same length. However, we should consider that adding edges differ from those of complete K-ary tree in length. This study proposes a model of adding edges between one node and every other node of the same depth N in a complete K-ary tree of height H when adding edges shorter than those of complete K-ary tree. The lengths of adding edges are L which is less than 1 while those of edges of complete K-ary tree are 1. This study formulates the total shortening distance of this model and obtains the optimal depth N* maximizing the total shortening distance.

3 - Murty's algorithm for semiassignment problem
Rosa Medina, Enrico Malaguti, Sebastian Rodriguez

The Semiassignment Problem tackles the minimization of the total cost of assignment of elements from one set to a smaller second set of elements with different capacities. The sum of the capacities of the elements in the second set must be equal to the number of elements in the first group. The problem can be solved in polynomial time and efficient algorithms exits to solve it. For some applications, the solution of minimum cost is not enough because there are characteristics on the assignment that are not quantitative or represented by the assignment costs. In addition, the number of solutions is a factorial function of the number of elements in the first set. In that cases, it is necessary to find a restrictive sequence of different solutions in non-increasing order of cost, to select from them the most suitable assignment. The purpose of this work is to adapt Murty's Algorithm to find a sequence of solutions without exploring symmetric assignments, which are a permutation of the capacities of the elements of the second set. The proposed algorithm is implemented and results are shown for instances of different sizes.

■ HB-23

Thursday, 10:30-12:00 - 2105

Rolling stock scheduling and routing

Stream: Optimization for public transport
Invited session
Chair: Denise Tönissen

1 - A propagation approach to acyclic rolling stock rotation optimization
Boris Grimm, Thomas Schlechte, Markus Reuther

The rolling stock, i.e., railway vehicles, are one of the key ingredients of a running railway system. As it is well known, the offer of a railway company to their customers, i.e., the railway timetable, changes from time to time. Typical reasons for that are different timetables associated with different seasons, maintenance periods or holidays. Therefore, the regular lifetime of a timetable is split into (more or less) irregular periods where parts of the timetable are changed. In order to operate a timetable most railway companies set up sequences that define the operation of timetabled trips by a single physical railway vehicle called (rolling stock) rotations. Not surprisingly, the individual parts of a timetable also affect the rotations. More precisely, each of the parts brings up an acyclic rolling stock rotation problem with start and end conditions associated with the beginning and ending of the corresponding period. We propose propagation approach to deal with large planning horizons that are composed of many timetables with shorter individual lifetimes. The approach is based on an integer linear programming formulation that propagates rolling stock rotations through the irregular parts of the timetable while taking a large variety of operational requirements into account. It is implemented within the rolling stock rotation optimization framework ROTOR used by DB Fernverkehr AG. Computational results for real world scenarios are presented to evaluate the approach.

2 - Multiple depot vehicle scheduling problem with controlled trip shifting
Lucie Desfontaines, Guy Desaulniers

We are interested in improving the classical Vehicle Scheduling problem with multiple depots by allowing a slight modification of departure schedules. By shifting some trips one can indeed expect to cover all trips with fewer vehicles and/or less expensive transit connexions. However, reducing operational costs this way should not be detrimental to the overall quality of departure schedules. Therefore our model controls these three criterions: the number of shifted trips, the interval between two same-line consecutive trips and the quality of passengers connexions. In order to solve this problem we propose two column generation based algorithms: an exact one and a heuristic one. We also apply several graph reductions which allow solving larger instances. Tests on real urban data show that slightly shifting some trips can yield to a significant reduction in the number of vehicles used.

3 - Recoverable robust maintenance location routing for rolling stock
Denise Tönissen, Joachim Arts

We consider the problem of locating maintenance facilities in a railway setting. We have a discrete set with capacities and associated fixed facility costs, for each maintenance facility, that can capture the economies of scale. Because of the strategic nature of facility location, this problem has to be feasible for the current situation, but also for any of the scenarios that can occur in the future. These discrete scenarios capture changes such as changes to the rolling stock schedule, up and down-scaling of service frequencies and the introduction of new rolling stock types. We allow recovery in the form of opening additional facilities, closing facilities and upgrading the facilities to a higher capacity for each scenario. We provide a two-stage robust programming formulation. In the first stage, we decide which facilities to open and their capacities, and in the second stage, we solve a NP-hard maintenance location routing problem. We reformulate the problem to a mixed integer program that can be used to make an efficient column-and-constraint generation algorithm that improves the computational time and can handle larger instances due to more efficient memory usage. Furthermore, we perform an extensive case study with data from the Dutch Railways.

■ HB-24

Thursday, 10:30-12:00 - 301A

Transportation logistics in healthcare

Stream: CORS SIG on healthcare
Invited session
Chair: Louis-Martin Rousseau
Chair: *Nadia Lahrichi*

1 - Analysis and optimization of patient external transportation in Montreal
Anne-Laurence Thoux, Elisa Dubois, Eva Petitdemange, Louis-Martin Rousseau, Nadia Lahrichi

Patient external transportation is a major portion of the budget of logistics in health care facilities in Quebec. Since April 1st 2015, the facilities of Montreal are merged into CIUSSSs (centre intégré universitaire de santé et services sociaux) which include several health care institutions. Therefore, these organizations have decided to use this context to uniformize their decision process regarding the booking and the choice of patient external transportation. Currently, these differ from place to place. Optimizing the transportation system itself will lead to a better balance between the quality of the transfers and their cost. In order to standardize, we design a support decision tool to help choose the right type of transportation and accompanying for patients. This tool is based on a decision tree built after several interviews with healthcare professionals. Once provided the request for transport, a dispatcher should decide which vehicle will be used and when. Different strategies for booking are tested using a simulation model. We also take advantage of the model to test routing scenarios, introduce new vehicles (such as internal fleet), and finally test levels of centralization. In particular, we investigate if serving the transport requests of all the health care facilities of Montreal with a unique network would provide high savings. This means adapting existing public transit network to fit the particular constraints raised by the context of the project.

2 - Simulation and optimization to improve health logistics and distribution networks
Nadia Lahrichi, Gabriel Madelin

The improvement of logistic processes is important for the efficiency of a system, and in health care systems such as hospitals the main logistic process is a distribution network. This article discusses using simulation to improve the distribution. We use the simulation model to test various scenarios and incorporate an optimization algorithm to find the best distribution routes. The results highlight concrete improvements that could be made. These are: the use of the same cart for different types of supplies to reduce the number of routes; the reduction of the distribution frequency for certain care units to reduce stock problems; and the use of optimized routes to reduce the transportation time.

3 - Using discrete-event simulation to support the management of an intrahospital transportation service
Valérie Bélanger, Maxime Painchaud, Angel Ruiz

Intrahospital transportation activities have to be performed daily to ensure smooth clinical pathways and avoid unwanted delays. These activities range from transporting inpatients with limited mobility from one location to another to moving samples from one care unit to the hospital laboratory. Regardless of their nature, all transportation activities need to be performed efficiently taking into account the use of costly resources (e.g. operating theaters) while maximizing the patient comfort and well-being. The specific requirements of each request, including their priorities, also have to be considered. In practice, patient and material transportation is often managed independently. Dealing with both types of requests in a centralized framework can result in an improved performance and a better use of resources. It also leads to a more complex decision-making process. Given the high level of uncertainty, especially with respect to patient transportation, adequate tools are required to help hospital managers plan and operate such a service. In this study, we propose a discrete-event simulation tool to support the management of an intrahospital transportation service. This proposed simulation tool considers both types of requests as well as several levels of priorities. The tool is validated in the context of a Canadian hospital, and used to evaluate and compare the system performance under several decisions, including dispatching policies.

■ HB-25

Thursday, 10:30-12:00 - 301B

OR application in wood supply management

Stream: CORS SIG on forestry
Invited session
Chair: Luc LeBel

1 - Application of the leagile strategy to maximise value generation in the forest products supply chain
Shuva Gautam, Luc LeBel

This study proposes the use of leagile strategy in wood procurement systems (WPS) to improve its capacity to deliver raw materials to a diverse set of manufacturers in the forest products supply chain. Leagile is a hybrid of two approaches, lean and agile, that entails strategically locating decoupling points based on the demand volatility of the product. The focus upstream of the decoupling point is on efficiency, while the downstream emphasis is on responsiveness. However, implementing the leagile strategy is a challenge in WPS characterised by divergent flows. High volumes of co-products and by-products are generated at multiple locations along the supply chain making it difficult to implement a specific strategy. A potential method to alleviate the problem is through permitting flexibility in silvicultural decisions which dictate the mix of assortments produced in the forest. Subsequently, implementing the leagile strategy would permit the WPS to efficiently satisfy demand. The objective of this study was to quantify WPS performance improvement attainable through implementation of the leagile approach, and permitting flexibility in silvicultural decisions. An optimization model was developed to support the preparation of monthly plans that satisfy demands from a diverse set of customers. Implementation of the model to a case study demonstrated a 3.4% and 3.8% increase in profit attributable to the leagile strategy and silvicultural flexibility, respectively.

2 - An assessment of the potential economic impact of preserving old-growth forest using different strategic forest management policies in the fire-prone boreal forest

Baburam Rijal, Luc LeBel, David Martell, Gauthier Sylvie, Jean-Martin Lussier, Frédéric Raulier

Old-growth forest is important for sustaining both biodiversity and the bio-economy but, fire disturbances and commonly used harvest practices can have adverse impacts on it. However, the impacts of the planning on the preservation of old-growth forest are less documented. The objectives of this study were to examine the impact of three harvest policies on preserving old-growth forest, and to evaluate their capacity to lower the adverse impacts on revenues with a constraint of preserving a minimum of 20% old-growth area. We constructed three strategic timber harvest-scheduling models. The models were simulated based on data obtained for three forests of distinct fire regimes. The model solutions without using the constraint did not help retain at least 20% old-growth area over a planning horizon. However, the proportions were slightly higher in model 3 (maximized processed timber revenue) than in model 1 (maximized timber volume). When we implemented the constraint, model 3 yielded the highest revenue with the least variation. Model 3 with the constraint yielded the revenue of $11.7 ha-1y-1 ($0 - 12.8 ha-1y-1) compared with model 1 ($6.4; 0 - 21.6 ha-1y-1) and model 2 (maximized timber revenue) ($6.3; 0.0 - 19.5 ha-1y-1). Model 3 increased probability of realizing feasible solutions to 0.87 - 1.0 compared with the probability of 0.71 -0.83 using model 1. Policy 3 helped retain old-growth forest with the least impacts on revenue with less risk.

3 - Implementation of a logistical center: Costs, benefits and deployment

François Sarrazin, Luc LeBel, Nadia Lehoux

The forest industry represents an important part of Canada's economic activity with about $20 billion in revenues annually. Concerns about environmental issues are putting greater pressure on this sector to review its practices, especially regarding the optimization of its transportation and sorting operations. In this vein, the creation of a sort and consolidation yard, distinct from the harvesting sites and the mills, can offer many opportunities for maximizing revenues and minimizing operational costs through more efficient sorting processes and the coordination of transportation. The objective of this research project is to choose the optimal site for the establishment of a logistical center comprising a sort yard and transportation coordination in the Mauricie region of the province of Quebec, Canada. We also measures the effect that the variations in the level of certain parameters have on the profitability of such center. To achieve this, we are proposing a profit maximization model for a forest products supply chain which can include a yard specifically dedicated to sorting while making possible the combining of different deliveries to diminish empty transportation returns. The model considers simultaneously the harvesting, transportation, sorting, production, and inventory operations. Such a modeling of a regional logistic center is seldom studied in the scientific literature, even though it may represent a mean to increase agility and cost efficiency.

■ HB-26

Thursday, 10:30-12:00 - 302A

Strategies in sports

Stream: OR in sports

Invited session

Chair: *Ryan Chen*

1 - Calculating MLB game outcomes using probability and regression analysis

Justin Long, Sarah Roudybush, Warren Geither

In today's world, mathematics and statistics have become a vital part of baseball. Regression analysis can be used to find variables positively correlated to winning, while probability can be used to predict outcomes of in-game events. Historical data from games dating back to 1934 will be sourced from retrosheets.org to develop model parameters. Our model extends current research by incorporating injury predictions and individual player strengths; including environmental conditions or historical performance against another player. The playing ability of each team is statistically assessed using starting lineup, player performance, as well as any potential substitutions. A user friendly interface facilitates input of a current game's data, accurately forecasting the winner along with the most likely final score. Based on model output, teams can adapt their playing strategy on a per-game or even per-inning basis, while fans can use it to satisfy their curiosity, or as a betting tool.

2 - Predicting NFL offensive play types with ensemble machine learning

Ryan Chen

We apply tools from machine learning to the burgeoning field of football analytics and predict whether a team will run or pass the ball on a given play. After training four different classification algorithms on data from the 2012-2014 NFL seasons, we developed an ensemble method that combines the predictions of our two best-performing individual models and achieved a test accuracy of 75.9%, improving upon previously published results. We also explored general trends in offensive predictability and found that teams are most predictable on late downs and in the fourth quarter. Finally, we conclude with an error analysis and assess whether our models could provide value to an NFL coaching staff.

3 - A DEA approach to measuring efficiency of a set of players of a baseball team and ranking players according to importance as a team member

Nobuyoshi Hirotsu

In this paper, we propose a method for evaluating a performance of a baseball player from the aspect of importance as a team member. For this purpose, we apply a data envelopment analysis (DEA) model to measure the efficiency of a set of 9 field players in the team. We use AB and GDP as the input, and H, HR, BB, SB and SB as the output, and introduce a link between the team and the players into the model. Following this method, individual players can be ranked by their reference frequencies according to the importance as a team member. We illustrate our method using annual data of the field players of MLB teams in the 2013 season, and show a concrete ranking of the players in the teams, which would be difficult to calculate without an application of the DEA model.

■ HB-27

Thursday, 10:30-12:00 - 302B

Optimization in renewable energy systems 1

Stream: Optimization in renewable energy systems
Invited session
Chair: *Serap Ulusam Seckiner*
Chair: *Fuzhan Nasiri*
Chair: *Alexia Marchand*

1 - Risk-averse optimization and sample average approximation for a virtual power plant
Ricardo Pinto de Lima, Loïc Giraldi, Antonio Conejo, Ibrahim Hoteit, Olivier Maître, Omar Knio

In this talk, we compare risk-averse optimization methods to address the self-scheduling and market involvement of a virtual power plant (VPP). The decision-making problem of the VPP involves uncertainty in the wind speed and electricity prices forecast. The electricity prices forecasts are sampled from an AutoRegressive Integrated Moving Average model, and the wind speed forecasts are based on a 51-member wind ensemble. Using the ensemble, we construct a Karhunen-Loeve expansion for sampling the wind speed. We focus on two methods: risk-averse two-stage stochastic programming (SP) and two-stage adaptive robust optimization (RO). We analyze both methods in terms of formulation, uncertainty and risk, and decomposition algorithms. To model the risk in SP, we use the Conditional Value at Risk (CVaR) because it resembles worst-case measures, which naturally links to RO. We analyze the computational performance of the decomposition algorithms used with SP and RO. We compare the operational results of the two methods with respect to the values of the first stage decision variables, and using Sample Average Approximation (SAA). For the latter, we adapt the risk-averse SP formulations to the standard formulation employed in SAA. The objective of using SAA is three-fold 1) to provide confidence intervals for upper and lower bounds on the objective function values; 2) to assess the quality of the first stage solutions; and 3) to compare first stage solutions from SP and RO.

2 - Forecasting distributed solar energy penetration using machine learning techniques: A study case for a Brazilian state
Gheisa Esteves

Introducing renewable energy sources on the countries electricity matrix has been a major issue not just on developed countries but also on developing ones. In Brazil, efforts for solar energy use are mainly directed to distributed solar energy generation, for both low and medium voltage consumers. Besides from building the regulatory framework to promote it, the country also need to define a hall of incentives to increase its use. Nevertheless, to develop and build an effective incentive strategy, it's important to know the potential for the energy source penetration. The main focus of the study is to conceive a model to estimate solar energy penetration using consumers electricity load behaviours aligned with computer intelligence techniques. As in Brazil, there is lack of real-time information about low and medium voltage consumer's load profiles, from four to four years, each Distribution Service Operators - DSO has the obligation of executing a measurement campaign to estimate its concession area typical loads profiles. The idea is to use information collected by a DSO to define the typical load profiles for low and medium voltage consumers per state applying techniques such as neural networks and genetic algorithms. And then to use a fuzzy logic approach to identify and classify the load profiles that had better match with the global radiation profile of the state studied.

3 - Least-squares Monte Carlo methods for hydropower optimization
Michel Denault, Pascal Côté, Nicolas Léveillé, Jean-Philippe Olivier-Meunier, Jean-Guy Simonato

We apply a least-squares, Monte Carlo dynamic programming approach to the problem of controling a hydropower system. Also called "simulation-and-regression", the approach is flexible and robust. We provide evidence derived from our collaboration with Rio Tinto on two of their systems in Canada.

4 - An effective neighborhood search for short-term planning of large-scale hydropower systems
Alexia Marchand, Michel Gendreau, Marko Blais, Grégory Emiel

Short-term hydro-generation scheduling aims at minimizing the energy consumption for the next 7 to 15 days on an hourly basis, while satisfying the electrical load as well as operational, regulatory and safety requirements, such as dams safety, grid operations, electrical reliability, units start-ups and shut-downs, flood control, environmental, recreational and maintenance constraints. In an ever-changing environment, planners need to take decisions quickly and often adapt their schedules to new conditions. They need a tool that is fast, reactive, and flexible. We present an effective neighborhood search with new neighborhood structures that quickly provides near-optimal solutions for short-term planning of Hydro-Québec's production system, one of the largest in the world. It can handle multi-objective problems, non-linear and non-convex constraints, as well as unfeasible solutions. We give numerical results on real instances of Hydro-Québec that also consider the wind and small hydro-generation plants.

■ HB-28

Thursday, 10:30-12:00 - 303A

Applications of OR 3

Stream: Applications of OR (contributed)
Contributed session
Chair: *Mohamed Abdulkader*

1 - A robust DEA-centric location-based decision support system for expanding recreovía hubs in the city of Bogotá (Colombia)
Lina Navas, Sepideh Abolghasem

Multi-sectorial community programs to promote healthy living in public spaces are crucial for building a "culture of health" and could contribute to achieving the specific 2030 agendas of Sustainable Development Goals including reduction of inequalities, provision of inclusive, safe, resilient and sustainable cities and promotion of just, peaceful and inclusive societies. In this context, the Recreovía program of Bogotá (Colombia) provides physical activity classes in parks mainly for vulnerable communities. Here, we address the challenge of efficiently locating new Recreovía hubs and to do this, we develop a robust DEA-centric location-based decision support system (DSS) for guiding the Institute of Sports and Recreation of District of Bogotá on locating the best hubs to expand the Recreovía program throughout the city. This DSS will serve as a model for analytics-based decision making for expanding equivalent programs in other cities.

2 - Pick-up and delivery with complex loading constraints: Application to the gasoline distribution
Bani Abderrahman, Issmail El Hallaoui, Correa Ayoub Insa

In this work, we present a Branch & Price method to solve a real-world pick-up and delivery problem arising in the sector of the distribution of gasoline. The underlying network consists of four distinct depots, a group of private carriers with heterogeneous tank trucks and five types of gasoline to replenish three groups of customers on a weekly basis. Complex loading and routing rules are handled in the sub-problem, a very difficult shortest path problem with resource constraints. Acceleration strategies will be discussed. Numerical results on real data show the high potential of the proposed approach.

3 - OR methods in engineering: Finding an optimal design of a hydrostatic transmission system between conflicting objectives
Lena Charlotte Altherr, Peter Pelz

Our chair being part of the department of mechanical engineering, we specialize in problem-suited modeling of fluid systems like ventilation or pump systems. We optimize their layout and control to reduce investment and energy costs with the help of OR methods. In this presentation, we will show how we designed a hydrostatic transmission system via Mixed Integer Programming. This system consists of a piston that is operated via a network of different valves. The system designer's task is to choose the type and the amount of valves and how to connect them. Ideally, such a technical system is highly reliable, without failures and down times due to fast wear out of single components. Dispersion of load between multiple valves can increase the system's reliability and thus its availabilty. However, this also results in higher investment costs and additional efforts due to higher complexity. Given a load profile and the resulting wear of the components, it is often unclear which system structure is the best trade off. For the engineering application example of the hydrostatic transmission system, we balance effort and availability and calculate the pareto front.

4 - Optimizing the distribution network of online shopping systems
Mohamed Abdulkader, Tarek ElMekkawy, Yuvraj Gajpal

The volume of online sales has been increasing tremendously. Giant retailing companies are competing to gain maximum customer satisfaction. They are selling products online along with their retail stores to maximize customer satisfaction. Therefore, online ordered products can be satisfied from the products available at nearby stores. Moreover, customers are allowed to select delivery time. In this work, we study the vehicle routing problem (VRP) in online shopping system distribution networks. This paper investigates the trade-off between cost minimization and customer satisfaction. This paper proposes solution approach to solve the resultant VRP problem. The effectiveness of proposed solution methods is evaluated through extensive numerical experiments.

■ HB-29

Thursday, 10:30-12:00 - 303B

Integration of intermittent and renewable energy sources

Stream: Long term planning in energy, environment and climate
Invited session
Chair: *Nadia Maïzi*
Chair: *Thibaut Cuvelier*

1 - Optimising workforce and energy costs by exploiting production flexibility
Thibaut Cuvelier, Quentin Louveaux

In a world where the electricity prices become more and more volatile, notably due to renewable energies, the industry is suffering from cost variations never seen before, especially when electro-intensive. Nevertheless, the plants can significantly reduce this impact: some electro-intensive factories could shift their production to time periods where the electricity is cheaper, resulting in large savings. At the same time, the grid operator can remunerate this consumption adaptation as a flexibility service. Our research goal is to optimise the operations of a factory around this flexibility. We compute a production plan that adapts to price forecasts, but also flexibility levers that adjust this plan to react to unexpected price changes. We propose the unifying concept of reservoir to provide sufficiently good models for the plant's processes. Nevertheless, this methodology implies to have frequent production plan changes, which directly impacts the workers, as they may be asked to follow barely predictable schedules. This has a significant detrimental effect on their quality of life. As a consequence, the human aspect of flexibility must also be considered: we seek for production plans that consider both workforce and energy costs, and we then assign workers to work shifts while ensuring their well-being. This HR orientation is the most innovative contribution of this research project.

2 - Maximizing intermitency in 100% renewable and reliable power systems: A holistic approach applied to Reunion Island in 2030
Nadia Maïzi, Vincent Mazauric, Edi Assoumou, Vincent Krakowski, Stephanie Bouckaert

We address long-term power system analysis taking a comprehensive, coherent approach based on MARKAL-TIMES models. To deal with specific operation conditions, we introduce a transient reliability indicator based on kinetic energy and adapt it to take into account flexibility solutions such as demand response and storage. To constrain operation conditions to their current levels over time, the kinetic indicator is endogenized within the model. In addition, we employ a dedicated Kuramoto model to address the synchronism condition required for aggregating the kinetic energy embedded in the whole power system. This analysis is illustrated by a case study of Reunion Island, which aims to reach energy independence by 2030 using 100% renewables. Although we find that the capacity to invest in the energy sector is doubled, we ascertain that the loss of reliability induced by higher intermittency - typically 50% - in the power mix can be counter balanced and leveraged by implementing flexibility solutions.

3 - Methodology for insertion of intermittent energy in Brazilian hydrothermal dispatch
Fernando Luiz Cyrino Oliveira, Paula Maçaira, Yasmin Cyrillo, Reinaldo Souza, Fabio Hideki Iha, Luiz Fernando Lorey

Brazil has almost 5k power generation projects in operation, totaling 161GW of installed capacity, where 66% is from hydroelectric power plants and 6% from intermittent generation sources(wind and solar). An addition of 25 GW is scheduled for the next few years in the country's generation capacity, where 43% of the installed capacity is from intermittent ones. Nowadays, planning the Brazilian energy sector means, basically, making decisions about the dispatch of hydroelectric and thermoelectric plants where the operation strategy minimizes the expected value of the operation cost during the planning period, which is composed of fuel costs plus penalties for failure in supplying the projected expected load. Given the growing trend of intermittent generation in the Brazilian energy matrix, it is necessary to include this type of generation in the dispatch currently used, so that this type of generation is effectively considered in the long term planning. This work aims to develop and apply a methodology called here of Net Demand calculation in order to incorporate intermittent generation in the calculation of the Brazilian hydrothermal dispatch using the analytical method of Frequency and Duration (F&D). In order to extract all the characteristics of intermittent generation, the data periodicity must be hourly, thus providing a model with greater accuracy. The results obtained show that the methodology is successful in including intermittent sources in the hydrothermal dispatch

4 - Real options in renewable portfolio standards
Makoto Goto, Ryuta Takashima

Recently policymakers have implemented various policies for reducing greenhouse gas emissions, due to concerns about global warming and climate change. Foremost policies for supporting and promoting renewable energy are feed-in tariff (FIT), and renewable portfolio standards (RPS). RPS scheme encourages power producers to supply a certain minimum share of their electricity from renewable energy sources. They create market for renewable energy certificates/credits. According to "Renewables 2016 Global Status Report" by REN21, RPS policies are conducted in 26 countries and 74 states/provinces/territories. RPS policies are popular at the sub-national level. Relationship between RPS scheme and market equilibrium is studied by Fischer

(2010), Tanaka and Chen (2013), Siddiqui, Tanaka, and Chen (2016). Boomsma, Meade and Fleten (2012) investigate investment timing and capacity sizing under different support schemes for renewable energy. In this paper, we examine a market equilibrium under uncertainty in RPS by means of real options analysis. More concretely, we analyze an investment timing for renewable producer. After that, we derive optimal RPS target. We have found results about the effect of uncertainty on market equilibrium and optimal RPS target. For fixed RPS target, investment opportunity increases (decreases) with RPS target (uncertainty). For the optimal RPS target, investment opportunity increases with uncertainty. This is a new finding in this area.

■ HB-30

Thursday, 10:30-12:00 - 304A

Health care management

Stream: Health care management
Invited session
Chair: *Michael Carter*
Chair: *Karmel Shehadeh*

1 - A Monte Carlo optimization framework for solving the colonoscopy scheduling problem under uncertainty
Karmel Shehadeh, Amy Cohn

When scheduling outpatients to a specialty clinic, complexity is introduced by the many sources of variability within the system. Scheduling colonoscopy patients in an endoscopy clinic yields an added complexity due to the pre-procedural bowel prep that the patient must undergo. The variation in the quality of the prep creates a unique bimodal duration structure of short and long procedures with high unpredictability. This contributes to a schedule with many outliers. Finally, there is an additional challenge from balancing competing objectives such as procedure quality, procedure delays, and working overtime. We use simulation and stochastic programming techniques to analyze and improve the scheduling of colonoscopy patients. Within a Monte Carlo optimization framework, we approximated the duration structure based on the likelihood of the type and analyzed the properties of an optimal schedule under different scenarios with respect to a weighted combination of performance metrics. We identified the structure of an optimal schedule as a function of system uncertainty. A simulation study confirmed the high performance of the proposed schedule when compared to traditional scheduling heuristics. Overall, the results suggest significant potential for an on-time schedule with few outliers, improved quality of treatments, and a decrease in overtime.

2 - Annual block scheduling for residency programs
William Pozehl, Amy Cohn

Despite significant advances in the application of optimization techniques to scheduling processes, scheduling for healthcare providers remains a practically complex challenge. Computationally, these problems present all the challenges of general scheduling problems coupled with personnel, education, and patient care needs. Moreover, these problems often feature many objective criteria by which their quality is measured. In the case of annual block schedules in residency, we have found linear programming models to provide a means for rapidly construction of high-quality schedules. Use of mathematical modeling offers numerous benefits to the program, residents, and patients. The programs benefit through reduced workload placed on leadership, enabling them to focus on ensuring the excellence of their training offerings. The residents benefit through improved satisfaction of their requests for services, vacations, and other experiences, thereby reducing the risk of burnout. Most importantly, the patients benefit through the ensured satisfaction of appropriate staffing and timely care.

3 - Fuzzy multicriteria model for selection of vibration technology in a health care organization: A case study
Maria Carmen Carnero

Health Care Organizations must have high levels of availability, quality and safety in their facilities and medical equipment. Nonetheless, despite the implications that the maintenance of these facilities has for quality of care and the lives of patients, the number of advanced maintenance policies introduced, such as predictive maintenance, is very small. The advantages of applying a predictive maintenance programme based on vibration analysis have become well known over recent decades. Although the literature includes a large number of contributions dealing with signal handling, diagnostic techniques, technical parameter analyses and prognosis, this is not the case with the instruments that guarantee the best results. Despite its importance, there are no models in the literature to aid in decision making. This research describes an objective model using the Fuzzy Analytic Hierarchy Process (FAHP) and Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (FTOPSIS) to select the best technology for vibration analysis to be applied to a Health Care Organization. The model includes the judgements of a number of decision makers who are experts in the area of vibration analysis.

■ HB-31

Thursday, 10:30-12:00 - 304B

OR promotion among academia, businesses, governments, etc.

Stream: Initiatives for OR education
Invited session
Chair: *Sue Merchant*
Chair: *Elise del Rosario*
Chair: *Gerhard-Wilhelm Weber*
Chair: *Kseniia Ilchenko*

1 - Ways of promoting OR in an ever-changing environment
Sue Merchant

No one ever said it was easy to promote OR to anyone! It is hard enough to explain to one's relatives what you as an OR person do, let alone communicate the breadth of the discipline to the wider world. Many OR societies have wrestled with this problem for years, some with more success than others, and they find it is necessary to give constant attention to the issue in today's rapidly changing world. Sue will review the different types of audiences there are and the methods which can be used to identify the most appropriate types of promotion which are needed for each, mentioning the efforts of the UK OR Society and others over the last decade or so , and reflect on which promotional approaches appear to have had most success in the UK.

2 - Promotion of OR in the Philippines
Elise del Rosario

This presentation will touch on the activities of the Operations Research Society of the Philippines in acquainting professionals in the academe, government and the private sector with OR. It will also touch on the experience of a company in getting OR better known in the various corporate departments. It will also touch on some practices of schools in getting students and the business community better acquainted with OR.

3 - Development and promotion of operational research in Nigeria
Olabode Adewoye

Operational research, management science or decision science is the science of system improvement that has contributed to growth and development of many countries. The aim of the work is to chronicle the development of operational research, its promotion and to establish if there is any relationship between OR awareness and O.R. applicability in Nigeria. Questionnaire was administered to some academic staffs of Some selected higher institutions within the country. Methods used included instrument development, an exploratory analysis, regression analysis. The results showed that there is less awareness of the field of OR.

Thursday, 13:30-14:30

■ HC-03

Thursday, 13:30-14:30 - 200AB

Plenary speaker: Andres Weintraub

Stream: Plenary sessions
Invited session
Chair: Celso Ribeiro

1 - OR practice matters
Andrés Weintraub

The field of OR can be viewed as a continuous arc going from pure methodology to applications. OR Practice can go from solving specific problems to changing the way an industry or organization handles its decision making. We can make a point that OR needs to have an impact in the real world. Besides, often highly interesting methodological challenges arise through solving real problems. The motivation for this talk is to show the work in our group, which has been involved in multiple successful projects in different areas: natural resources (forestry, mining, aquaculture), logistics, sports scheduling, governmental organizations. The talk does not intend to be a short presentation of multiple projects but more to present a view on how to integrate OR, data handling, organizational behavior to get a handle on what the real problems are, how to integrate management in the development of solutions and how to implement systems that have impact. As a showcase, the talk will present parts of presentations of an IFORS OR in Development winner, one Edelman winner and two additional finalists, all in different areas.

Thursday, 15:00-16:30

■ HD-01

Thursday, 15:00-16:30 - 307B

Applications of Benders decomposition

Stream: Telecommunications and network optimization
Invited session
Chair: Bernard Fortz

1 - Benders Decomposition for the network design problem with vulnerability constraints
Martim Joyce-Moniz, Luís Gouveia, Markus Leitner

The Network Design Problem with Vulnerability Constraints (NDPVC), which was recently proposed by Gouveia and Leitner [EJOR, 2017], simultaneously imposes resilience against failures (network survivability) and bounds on the lengths of each communication path (hop constraints). Solutions to this problem are subgraphs containing an (s-t)-path of length at most H(s,t), for each commodity s,t, as well as (s-t)-paths of length at most H'(s,t) after at most k-1 edge failures. The authors show that the NDPVC is less conservative than a well-known problem in the literature, the Hop-constrained Survivable Network Design Problem, which often produces costly solutions, and may even fail to provide feasible solutions. The authors propose several mixed-integer programming models for the NDPVC. However, the computational results reveal that even when implementing the models capable of producing the tightest linear programming bounds, CPLEX struggles to solve most instances to optimality. In this presentation, we propose a branch-and-cut algorithm for the NDPVC, based on the Benders decomposition of the most promising models proposed for the NDPVC. Moreover, we discuss some improvements for this algorithm, namely a primal heuristic, and the use of connectivity cuts to improve the initial bounds. We show that this method is significantly more efficient in solving the NDPVC than CPLEX's standard solving methods on the same models, and that this allows us to solve many more instances.

2 - A Benders decomposition based framework for solving cable trench problems
Martin Luipersbeck, Hatice Calik, Markus Leitner

In this work, we present an algorithmic framework based on Benders decomposition for the Capacitated p-Cable Trench Problem with Covering. We show that our approach can be applied to most variants of the Cable Trench Problem (CTP) that have been considered in the literature. The proposed algorithm is augmented with a stabilization procedure to accelerate the convergence of the cut loop and with a primal heuristic to derive high-quality primal solutions. Three different variants of the CTP are considered in a computational study which compares the Benders approach with two compact integer linear programming formulations that are solved with CPLEX. The obtained results show that the proposed algorithm significantly outperforms the two compact models and that it can be used to tackle significantly larger instances than previously considered algorithms based on Lagrangean relaxation.

3 - Using variables aggregation and Benders decomposition for solving large-scale extended formulations
Bernard Fortz, Markus Leitner

Many optimization problems involve simultaneous decisions on high-level strategic decisions such as the location and/or dimensioning of facilities or devices, as well as operational decisions on the usage of these facilities. Moreover, these decisions often have to be taken for multiple demand sets over time or in an uncertain setting where multiple scenarios have to be considered. Hence, a large number of variables (and constraints) is often necessary to formulate the problem. Although sometimes more compact formulations exist, usually their linear relaxations provide much weaker lower bounds, or require the implementation of problem-specific cutting planes to be solved efficiently. A lot of research has focused in recent years on strong extended formulations of combinatorial optimization problems. These large-scale models remain intractable today with traditional solvers, but Benders decomposition gained attention as successful applications of it have been reported. An alternative to these large-scale models is to use more compact formulations, often based on variable aggregations. We propose an intermediate strategy that consists of projecting the extended formulation on the space of aggregated variables with a Benders decomposition scheme, applicable to a large class of problems.

■ HD-02

Thursday, 15:00-16:30 - 308B

Analysis and decision making in queues 2

Stream: CORS SIG on queueing theory
Invited session
Chair: Gennady Shaikhet

1 - Choosing how to optimally parallelize jobs
Benjamin Berg

Running jobs in parallel is an excellent way to reduce their mean response time of jobs. In typical applications, such as jobs running on a multi-core machine, the *user* chooses the level of parallelization for her jobs. We propose instead that the *system* should choose the optimal level of parallelization so as to minimize mean response time across jobs. We show that this optimal level of parallelization, k*, is significantly affected by many variables, including the system load, the speedup function for the workload, the job size distribution, the particular dispatching policy used for assigning jobs to servers, and by the scheduling discipline at the servers. We provide analysis for determining k* given all the above parameters. One of the most interesting findings of our work is that a static level of parallelization suffices. Specifically, one might imagine that a system should dynamically choose the level of parallelization for a job based on the current system state (number of jobs). Such a dynamic parallelization scheme is not practical, yet interesting theoretically. Our work shows that the right static level of parallelization yields similar performance to this idealized dynamic parallelization scheme. Joint work with: Jan-Pieter Dorsman and Mor Harchol-Balter

2 - Optimal traffic schedules
Harsha Honnappa, Mor Armony, Rami Atar

We consider the problem of optimally scheduling a finite, but large, number of customers over a finite time horizon at a single server FIFO queue, in the presence of 'no-shows'. We consider fluid and diffusion approximations to the stochastic optimization problem defining the scheduling problem; it is well known that the latter is not straightforward to solve. We study the problem in a large population limiting regime as the number of customers scales to infinity and the appointment duration scales to zero. We show that in the fluid scaling heavy-traffic is obtained as a result of asymptotic optimization. We also identity an asymptotically optimal sequence of fluid-scaled schedules that achieve the value of a posited fluid optimization problem. The fluid-optimal solution indicates that the stochastic optimization problem could be approximated by an equivalent Brownian optimization problem. We prove that when the finite time horizon is large enough, the optimal diffusion schedule is a linear drift function of a stationary reflected Brownian motion. Finally, we identify a sequence of diffusion-scaled schedules that achieve the value of the Brownian optimization problem.

3 - Equilibrium behavior of randomized load balancing algorithms
Pooja Agarwal

Randomized load balancing algorithms play an important role in large-scale networks. Many such algorithms have been extensively analyzed in the case of exponential service times. In contrast, the practically relevant case of general service times has received less attention. Under fairly general conditions on the service distribution, recently a hydrodynamic limit was established for the join-the-shortest-of-d-queues routing algorithm that describes the system dynamics as the number of servers goes to infinity, in terms of a system of coupled measure-valued processes. We prove existence of a unique equilibrium point for these hydrodynamic equations. We also discuss some properties of these equilibrium points, and their implications for the performance.

■ HD-03

Thursday, 15:00-16:30 - 200AB

Keynote speaker: Ulrike Leopold-Wildburger

Stream: Keynote sessions
Keynote session
Chair: Gerhard-Wilhelm Weber

1 - Operations research and behavioral economics
Ulrike Leopold-Wildburger

While operations research represents the field of a science for delivering better decisions using optimal (or near-optimal) solutions to complex decision-making problems our behavior in practical applications quite often has to deal with non-fully rational decision makers. The tension between the two scopes shall be worked out and supported by a series of examples. Coming from the field of OR we are aware that that techniques such as mathematical modeling, statistical analysis, and mathematical optimization are engaged in applications of advanced analytical methods with the aim to make better decisions. However, in everyday life OR is not executed in its pure version but often connected with other fields and disciplines, as psychology and behavioral sciences, integrating neuroscience and microeconomics. Some characteristic examples from the field of game theory will be prepared and checked with the actual behavior of decision makers in specific economic situations. We will deal with topics as cooperation, fairness and honesty and we will try to compare theoretical concepts with empirical data.

■ HD-04

Thursday, 15:00-16:30 - 202

Challenging applications in derivative-free optimization

Stream: Derivative-free optimization
Invited session
Chair: Ana Luisa Custodio

1 - Hull-form optimization via hybrid global/local multi-objective derivative-free algorithms
Riccardo Pellegrini, Andrea Serani, Giampaolo Liuzzi, Stefano Lucidi, Francesco Rinaldi, Emilio Fortunato Campana, Matteo Diez

The development and application of hybrid global/local multi-objective derivative-free algorithms are presented, for hull-form optimization in ship hydrodynamics. Two well-established derivative-free global algorithms, namely particle swarm optimization (PSO) and DIviding RECTangles (DIRECT), are extended to multi-objective problems and combined with derivative-free multi-objective (local) line-search methods. A systematic assessment of the algorithms' performance is carried out based on the hyper volume metrics and used to investigate the global/local hybridization strategy and the tuning parameters involved. Benchmark problems include analytical test cases and two hull-form optimization problems of a high-speed catamaran and a surface combatant, performed with the aim of reducing the resistance and increase the operability in a realistic operating scenario. Hybrid extensions of PSO and DIRECT provide wider Pareto fronts than their global counterparts and are shown to be a viable option for multi-objective hydrodynamic optimization.

2 - Scenario tree modeling for stochastic short-term hydropower operations planning
Sara Séguin, Charles Audet, Pascal Côté

Scenario trees are widely used, in the field of hydropower optimization, to treat uncertainty of the water inflows of the reservoirs. Many scenario tree generation methods require input parameters to determine the structure of the trees. In this case, number of nodes per stage, number of stages and aggregation of the time period of each stage are input parameters. Blackbox optimization is used to determine the input parameters of the scenario trees that maximize the energy production of a short-term hydropower optimization model. The blackbox contains a stochastic nonlinear problem and a stochastic linear integer problem that are solved using a rolling-horizon framework. The solution to the short-term model using scenario trees is compared to the solution of the same model using scenario fans. The advantage of scenario fans is that the only parameter on the structure is the number of scenarios. The method is tested on three hydropower plants located in Saguenay, Canada. Numerical results suggest that using a set of scenario fans yields a comparable solution to using scenario trees with less computational effort.

3 - Hybrid parallel derivative-free optimization for machine learning problems
Steven Gardner, Oleg Golovidov, Joshua Griffin, Patrick Koch, Scott Pope

With the exponential growth rate of digital data the challenge of managing, understanding, and capitalizing on this data also continues to grow. Facilitating effective decision making requires the transformation of relevant data to high quality descriptive and predictive models. Machine learning modeling algorithms are commonly used to find hidden value in big data. These algorithms are governed by hyper-parameters with no clear defaults agreeable to a wide range of applications. Ideal settings for these hyper-parameters significantly influences the resulting accuracy of the predictive models. In this talk we discuss the use of derivative-free optimization for hyper-parameter tuning. As a complex black-box to the tuning process, machine learning algorithms are well suited to derivative-free optimization for tuning. We employ a Local Search Optimization (LSO) procedure, which performs parallel hybrid derivative-free optimization for problems with functions that are nonsmooth, discontinuous, or computationally expensive to evaluate directly. LSO permits both continuous and integer decision variables, and can operate in single machine mode or distributed mode. We will present tuning results for multiple examples, compared to default model training, and discuss and demonstrate the use of distributed processing to reduce the tuning expense.

■ HD-05

Thursday, 15:00-16:30 - 203

Dynamic programming 1

Stream: Dynamic programming
Invited session
Chair: Maxime Ogier

1 - Dynamic programming based algorithms for the temporal knapsack problem
François Clautiaux, Boris Detienne

Our work is about new methods for solving the temporal knapsack problem. This is a generalization of the well-known knapsack problem, where any selected item consumes the capacity only during a certain time interval. We study several dynamic programming formulations for this problem. Each formulation is solved by a procedure that embeds forward labelling, lagrangian relaxation, and an iterative disaggregation algorithm. All formulations are compared empirically against instances from the literature.

2 - Approximate dynamic programming for planning driverless fleets of electric vehicles
Lina Al-Kanj, Warren Powell

By year 2021, almost every major auto company, along with fleet operators such as Uber and Lyft, have announced plans to put driverless vehicles on the road. At the same time, electric vehicles are quickly emerging as a next-generation technology that is cost effective, in addition to offering the benefits of reducing the carbon footprint. The combination of a centrally managed fleet of driverless vehicles, along with the operating characteristics of electric vehicles, is creating a transformative new technology that offers significant cost savings with high service levels. This problem involves a control problem for assigning requesters to cars, a planning problem for deciding on the fleet size and a pricing problem all of which are high dimensional stochastic dynamic programs. In this work, we propose to use approximate dynamic programming to develop high-quality operational control strategies to determine which car (given the battery level) is best for a particular trip (considering its length and destination), when a car should be recharged, and when it should be re-positioned to a different zone which offers a higher density of trips. We then propose to use outputs (in the form of value functions) from the operational planning model to optimize the distribution of battery capacities in the fleet. We wish to determine the number of cars required to provide a high level of service, and from this to understand the economics of a driverless fleet of electric vehicles.

3 - A heuristic approach to solve an integrated warehouse order picking problem
Maxime Ogier, Martin Bue, Diego Cattaruzza, Frédéric Semet

In this abstract we address an integrated warehouse order picking problem. The warehouse is divided in the picking and the storage areas. We focus on the picking area. It contains a set of aisles, each composed by a set of storage positions. For each period of the working day each position contains several pieces of a unique product, defined by its reference. The warehouse is not automated, and the order pickers can prepare up to K parcels in a given picking route. For each period of the working day a set of customers orders has to be prepared. An order is a set of product references, each associated with a quantity, i.e. the number of pieces required. The problem consists in jointly deciding: (1) the assignment of references to storage positions in the aisles which need to be filled up; (2) the division of orders into several parcels, respecting weight and size constraints; (3) the batching of parcels into groups of size K, that implicitly define the routing into the picking area. The routing is assumed to follow a return policy, i.e. an order picker enters and leaves each aisle from the same end. The objective function is to minimize the total routing cost. In order to deal with industrial instances of large size (considering hundreds of clients, thousands of positions and product references) in a short computation time, a heuristic method based on the split and dynamic programming paradigms is proposed. Experimental results will be presented.

■ HD-06
Thursday, 15:00-16:30 - 204A

NSERC/CRSNG special session

Stream: NSERC/CRSNG special session
Invited session

■ HD-07
Thursday, 15:00-16:30 - 204B

Exact methods for routing 2

Stream: Vehicle routing
Invited session
Chair: Stefano Michelini

1 - Formulations for location arc routing problems
Jessica Rodríguez-Pereira, Elena Fernandez, Gilbert Laporte

Location and arc routing problems have been, and remain, as recurring problems, widely studied. Although these are two closely related problems, in most real situations, traditionally, they have been tackled independently. In this work we consider several models for combined location and arc routing, in which nodes must be selected where facilities may be established, and routes must be designed to serve a given set of required edges. The basic model considers the optimal location for a fixed number of facilities in order to minimize the overall routing cost. Other studied models consider the minimization of the length of the longest route, a capacity constraint on the cardinality of edges served from an opened depot, as well as the combination of the both previous models. Optimality conditions are studied and alternative formulations based on these conditions are proposed. To solve the problems, we present an exact branch-and-cut algorithm. Finally, numerical results from a series of computational experiments on a large set of benchmark instances are presented to analyse the behaviour of the proposed method.

2 - Robust multi-period vehicle routing problems under customer order uncertainty
Chrysanthos E. Gounaris, Anirudh Subramanyam, Frank Mufalli, José M. Laínez-Aguirre, Jose Pinto

Several transportation problems involve the tactical planning and routing of vehicles over a multi-period planning horizon. In such settings, customer requests for service are received dynamically over the horizon, and the aim is to determine a minimum cost visit schedule and period-specific routing plans for a fleet of capacity-constrained vehicles. Almost all existing approaches to address such problems ignore the uncertainty stemming from potential requests for service that arrive in the future, leading to situations which can either be infeasible or too expensive in terms of routing costs. In order to guarantee the generation of robust plans that can flexibly accommodate future potential requests for service, we treat the latter as binary random variables and aim to determine a minimum cost visit schedule that remains feasible for all anticipated realizations of service requests. We model this decision-making process as a two-stage robust optimization problem and propose a novel integer programming formulation and a branch-and-cut solution approach. We analyze the performance of the two-stage model by deriving a valid lower bound on the associated multi-stage, fully adaptive solution, and we present numerical schemes for its computation. Computational experiments on instances derived from standard benchmark datasets show that our approach is practically tractable and generates high quality robust plans at marginal cost increases above the nominal plan.

3 - Branch-and-price algorithms for a VRP with time windows and variable departure times

Stefano Michelini, Yasemin Arda, Hande Kucukaydin

We investigate several solution methodologies for a variant of the VRP with time windows. In the examined variant, the departure time of each vehicle from the depot can be determined by the decision-maker, who aims at minimizing the overall duration of the routes, including waiting times, while respecting the maximum allowed working duration of each vehicle. In order to solve this problem using a branch-and-price (BP) methodology, we propose an adapted bidirectional labeling algorithm for the associated pricing problem, an elementary shortest path problem with resource constraints (ESPPRC). Various improvements for this labeling algorithm have been studied in the literature. We consider in particular decremental state space relaxation and ng-route relaxation. We develop several BP procedures based on the application of these two techniques and of others derived from their hybridization. Each algorithm considers either elementary routes or ng-routes; we treat these two classes of algorithms separately. For each BP procedure, several algorithmic strategies are considered and parametrized. The parameters are then tuned using an automatic algorithm configuration tool, the irace package, and the best configurations are finally compared. Lastly, we discuss how these BP procedures can be included as components in the development of a matheuristic.

■ HD-08

Thursday, 15:00-16:30 - 205A

Portfolio planning in weather and energy

Stream: Decision analysis
Invited session
Chair: Destenie Nock

1 - Building a portfolio of weather risk transfer contracts: Contrasts with natural catastrophe contracts and implications for reducing risk to the vulnerable
Samuel Bodily, D. Matthew Coleman

Natural catastrophes have increased in frequency and magnitude and weather variability continues to grow. Natural catastrophe risk contracts have served to reduce risk to counterparties, encouraging governments and individuals to invest in economic activities. In some ways weather risk transfer contracts are a more attractive business than the natural catastrophe risk business. While natural catastrophe risks that are independent of one another can be found, weather risks that are negatively correlated can be identified and combined in an investment portfolio. We use Monte Carlo simulation and systems analysis to compare the two businesses with regard to their portfolio diversification possibilities. The results are that weather risk transfer contracts can be combined more efficiently into a less risky portfolio. The implications of these findings are that vulnerable groups on the planet can find some cheaper avenues to reduce their risk and lower the impact of unfavorable weather.

2 - Improving rural electricity system planning: An agent-based model for stakeholder engagement and decision making
Jose Alfaro

Policy makers in developing countries face connected issues that can be impacted by the provision of electricity such as job creation, incentivizing the economy, and protecting the environment. These choices are made more complex when considering the appropriate level of grid decentralization and the type and place of resources to deploy. We present an Agent-Based Model that facilitates stakeholder engagement to better inform their decisions and explore what-if scenarios. The approach includes levelized cost of electricity, fuel portfolio, jobs created, community internal economic flows, and decentralization mix with a geographically resolved format for consideration of micro-grids. The work presented is not intended to replace traditional methods of electricity planning, but instead to complement such efforts by offering novel evaluation criteria based on typical strategies followed by decision makers. To demonstrate the approach, we present a case study based on Liberia, West Africa, presenting a blank slate scenario where no existing power systems or transmission infrastructure are considered. We develop five scenarios that reflect common practices in rural electrification: deploying large resources and using them to exhaustion, electrifying large populations first, using renewable energy to incentivize job creation, using renewable energy to incentivize community economic development, and step-wise cost minimization.

3 - Ancillary service revenues in a high renewable future
Todd Levin

Increasing variable generation (VG) in the U.S. power system has been shown to 1) depress wholesale electricity prices due to near-zero marginal generation costs, and 2) increase system reserve and flexibility requirements. As a result it is possible that future generation resources will receive a larger fraction of their revenues through ancillary service (AS) markets as opposed to electricity markets. We apply AURORAxmp, a commercial power systems model, to forecast how AS prices are affected under several different future scenarios and parameter sensitivities. A case study of PJM is conducted and a baseline scenario is first calibrated based on historical 2015 data. The model is then executed to optimize one year of unit commitment and dispatch over 8760 hourly time steps for each scenario, generating corresponding hourly energy and AS prices. Our results indicate that AS prices in PJM are strongly affected by changes in natural gas prices, but less strongly impacted by increased wind generation and reserve requirements. We also find that outages, planned or unplanned, at key generation units can lead to short periods of relatively high AS prices. Finally, we project revenue potential from both energy and AS for different unit types under these future scenarios. These results can inform investors, policy makers, and system operators, helping to ensure that markets are designed to appropriately incentivize system reliability and resource adequacy.

4 - Multi-criteria decision analysis of natural gas pipeline capacity expansion in New England: Impacts on the overall system sustainability
Destenie Nock, Erin Baker

As of 2016 natural gas plants represented 44% of the generation capacity on the New England power system. The availability of natural gas for electricity purposes is limited by the high dependence on natural gas in the winter, and the constraints surrounding the natural gas pipeline. This combined with proposed large scale development of offshore wind poses challenges to ensuring the reliability of the New England Power System. In this paper we first identify a set of portfolios with varying generation mixes, but each having the same level of overall reliability. We then evaluate the sustainability of each portfolio using a multi-criteria decision making framework. Using the results of this study the case is made for whether or not New England should expand its natural gas pipeline, build new transmission to Canada to allow for increased hydro capacity, or continue using liquefied natural gas and existing oil-based peaker plants.

■ HD-09

Thursday, 15:00-16:30 - 205B

Simulation-based approaches in management and economics

Stream: Simulation in management accounting and control
Invited session
Chair: Stephan Leitner

1 - An agent-based variant of the standard hidden-action model
Stephan Leitner, Friederike Wall

We transfer the hidden-action problem defined in the standard agency framework into an agent-based model consisting of three agents in terms of agent-based modeling: the principal, the agent and the environment. In line with the neoclassical model, in our model a delegation relationship between the principal and the agent exists which is defined in terms of a contract. The principal delegates a task to the agent who, given the contract appears attractive from her point of view, selects an effort-level to carry out the task. The delegation relationship exists in the environment, which affects the task's outcome. We retain the information assumptions incorporated in the neoclassical model, i.e., information asymmetry only exists with respect to effort-level selected by the agent. We endow the principal and the agent with a memory and the ability to learn about the environment over time. In addition, we limit the principal's ability to oversee the entire space of possible effort-levels at one time-step and endow him with a propensity towards innovation. This propensity, together with expectations about the environment, drives the principal's decision whether to perform a local or a global search for effort-levels that increase performance. Our results indicate that, in most cases, the search strategy does not affect the level of achieved performance. In addition, we identify factors that drive the level of achieved performance and speed of performance improvement.

2 - Allocation of procurement volumes in a buyer-supplier model
Kristian Strmenik

Besides selecting suitable suppliers, the allocation of buyers‘ procurement volumes is one of the key issues in supply chain management when following a multiple sourcing strategy. In order to allocate the procurement volume different indicators, like price, on-time delivery, quality, etc. are employed in research. This paper introduces a model, which captures the quality of the delivered goods of each supplier and a supplier quantity-quality trade-off, which reflects the responsiveness of quality to changes in volume. The trade-off is based on the assumption, that suppliers are not able to maintain the same level of quality if quantity increases. Considering heterogeneous quality settings it is analyzed, how the market shares of the suppliers change over an observation period when systematically changing the quantity-quality trade-off level exogenously. To answer this research question an agent-based simulation is conducted, which is an appropriate approach to study systems of heterogeneous and interacting agents (e.g., interactions between suppliers). The first research findings suggest that with a relatively, though not extremely high quantity-quality trade-off stronger fluctuations regarding the supplier market shares occur during the first time steps of the observation period - no matter the initial supplier quality. Consequently, the shifting of market shares lasts over more time steps compared to low or extremely high quantity-quality trade-off levels.

3 - Effects of population scenario on sustainability of the Japanese pension system
Michael Krause, Masanori Ozawa, Tadashi Uratani

The Japanese government has two main pension systems dating from 1947: the national pension (NP) and the employees' Pension Insurance (EPI). Japanese men and women have a long average life span. Nevertheless, many reports predict a declining population in long-term estimations because of low fertility. As a result, the reserve funds on the NP and EPI are shrinking every year. Therefore, the government has reported actuarial valuation of the pension systems every fifth years since 2004. In the last report, the key factors of pension evaluation were macroeconomics scenarios and population scenarios. The different population scenarios are based on variations in the fertility label and mortality label, which each factor has only 3 labels. To investigate the relationship between the population scenarios and the reserve funds, we formulate the pension financial balance and study the sustainability of the pension system with stochastic simulations under many population scenarios.

■ HD-10
Thursday, 15:00-16:30 - 205C

Facility location problems

Stream: Location
Invited session
Chair: *Katarzyna Krupińska*

1 - A dynamic shelter location and evacuation planning model for flood disasters
Maria Paola Scaparra, Melissa Gama, Bruno Filipe Santos

This work presents a multi-period optimization model to support evacuation operations during flood disasters. The model identifies where and when to open a predefined number of shelters, when to send evacuation orders, and how to assign evacuees to shelters over time. The objective is to minimize the overall network distances that evacuees have to travel to reach the shelters. The model takes into account that travel times vary over time depending on the road conditions. Evacuees demand for shelters is also considered to be dynamic and dependent on the timing of the warning signals. We also assume that shelters become available in different time periods and have a limited capacity. We present a mathematical formulation for this model which can be solved using an off-the-shelf commercial optimization solver, but only for small instances. To solve real size instances efficiently, a simulated annealing heuristic is proposed. The heuristic performance is evaluated on a set of random problems. The applicability of the multi-period model is illustrated using a case study which highlights the importance of adopting a dynamic approach for optimizing emergency response operations.

2 - Multi-type, multi-zone facility location
Andries Heyns, Warren du Plessis

A popular problem within the domain of location science is the placement of facility networks according to geospatial requirements. Typical objectives that are considered include dispersion, centre, and covering objectives, which are generally defined in terms of distance or service-related criteria. With few exceptions, existing facility location models only consider one type of facility to be placed within one placement zone. This approach, however, is becoming outdated, since networks that consist of more than one facility type become increasingly common. Examples include multi-type observation camera networks for forest fire detection and multi-type weapon system networks with various engagement efficiency requirements. However, it is expected that the placement zones may differ for each type of facility that is considered in a facility network siting problem. This is due to the unique placement requirements of different facility types - such as suitable terrain that may be considered for placement and specific placement objectives for each facility type - which has, thus far, not yet been considered in the facility location literature. In this study, we introduce the novel concept of multi-type, multi-zone facility location. A heuristic solution approach is proposed, for which a novel multi-type, multi-zone variation of the NSGA-II algorithm is presented and employed to solve practical examples of multi-type, multi-zone facility location problems.

3 - Preferential description of robust locations
Katarzyna Krupińska

We consider the problem of locating facilities on a directed graph in which costs connected to arcs are uncertain. We consider two different descriptions of uncertain arcs costs: in the first, to each arc is assigned a vector of costs related to a finite set of scenarios, in the second description, uncertain cost may be any number from an interval of possible values. We define a binary relation on the power set of the set of arcs and, in each case of uncertainty, we search for preferred locations which may be considered 'good' in the sense of predefined requirements listed as some properties satisfied by the preference relation. We also try to give an operational description of a predefined concept of a robust preferred location.

■ HD-11

Thursday, 15:00-16:30 - 206A

Forward and reverse supply chain design

Stream: Supply chain management
Invited session
Chair: Davoud Ghahremanlou

1 - Exact and heuristic approaches to a real-world multi-period network design problem
Roland Braune

We address a multi-period network design problem for strategic-tactical planning of material flows between plant locations of a manufacturing company. Transport capacities on edges can be allocated in integer multiples of a base capacity that corresponds to a single truck load. The number of truck loads that can be moved between two nodes in the network depends on the driving time. A single truck may serve multiple connections during a time period (usually a working day). The total number of trips is limited by the truck's temporal availability (typically 8 hours per day), but it can be extended by renting additional trucks at (high) fixed costs. The network nodes allow for the limited storage of goods over time and impose handling capacity constraints on both inbound and outbound flows. While the number of nodes and their geographical spread is relatively small, the complexity of the problem mainly arises from the time horizon length (6-8 weeks) and the huge number of commodities. We therefore present time and commodity aggregation schemes as a starting point for iterative, multi-level refinement heuristics. The problems occurring at different aggregation levels are solved using a mixed integer programming formulation. Furthermore, we investigate the performance of a Benders decomposition approach building upon a time-expanded problem representation and incorporating adaptations of valid inequalities originally proposed for the closely-related network loading problem.

2 - Dynamic reverse supply chain design for durable products under uncertainty
Masoumeh Kazemi Zanjani, Mohammad Jeihoonian, Michel Gendreau

Designing reverse supply chain (RSC) networks for modular-structured products is a complex problem as this category of products can be dissembled into several components. Depending on the category and quality status of each component, a particular recovery process would be desired to reclaim the economic value residing in the components. This study addresses a RSC network design problem in a multi-period setting to accommodate fluctuations in quantity of end-of-life products over a planning horizon. Given the critical impact of uncertainty on design decisions, the quantity of the return stream is defined as a random variable represented as a scenario tree. Hence, the problem of interest is modeled as a multi-stage mixed-integer program (MS-MIP). On the methodological side, a heuristic inspired by a scenario clustering decomposition scheme is developed to solve the model. The prime idea of this algorithm is to divide the scenario tree into a set of sub-trees such that they share some ancestor nodes. The MS-MIP model would consequently be broken down into smaller sub-models corresponding to each sub-tree. Then, the scenario cluster sub-models are coordinated by Lagrangian penalty terms in the objective function and a progressive hedging-based scheme is applied to update Lagrangian multipliers. Since each scenario cluster sub-model per se is a hard to solve problem, an accelerated Benders decomposition-based algorithm is also developed to solve each scenario cluster sub-model.

3 - Coordinated facility location, inventory and pricing decisions in a closed loop supply chain
Onur Kaya, Büsra Ürek

We analyze a network design problem for a closed-loop supply chain that integrates the collection of the used products with the distribution of the new products considering the inventory, pricing and incentive determination problems. We present a mixed integer nonlinear facility location-inventory-pricing model to decide on the optimal locations of the collection and distribution centers, optimal inventory amounts to be carried at these centers, optimal prices for new products and the values of incentives that need to be offered for the collection of right amount of used products, in order to maximize the total supply chain profit. We develop several heuristics and provide an upper bound for the solution of this model. We analyze the effectiveness of these heuristics and the effects of the parameters on this system through numerical experiments. We also present and solve an example of the problem using real life data.

4 - Effects of blend wall and government policies on the petroleum supply chain
Davoud Ghahremanlou, Wieslaw Kubiak

It is more than a decade biofuel has been the center of attention for government and investors. The US government policies have been accelerating growth in the production of biofuels which exceeded the blend wall in 2016. Since biofuel and petroleum gasoline are blended to fulfill the gasoline engine vehicles' fuel requirements, the production of the biofuels has great impact on the Petroleum Supply Chain (PSC). We present a two stage stochastic programming model to find the optimum design and operation for the PSC. The effects of the changes in the government policies and blend wall on the supply chain are then analyzed with the model.

■ HD-12

Thursday, 15:00-16:30 - 206B

Timetabling

Stream: Timetabling and project management
Invited session
Chair: Shana Van Dessel

1 - Towards more configurable and interactive timetabling tools using a knowledge-based approach
Shana Van Dessel, Pieter Smet, Joost Vennekens

The timetabling literature focuses on developing computationally efficient ways of generating a new timetable from scratch. However, users may be unsatisfied with current timetabling tools for reasons that have nothing to do with the computational efficiency of the algorithms that perform this task. In this study, we report on a series of interviews conducted with the timetabling staff of a number of secondary schools in Belgium. The results reveal that, even though the staff has commercial timetabling tools available, they still perform a large portion of the task by hand. There are two reasons for this. First, not all of the relevant constraints can be expressed in the tools. Second, they view timetabling as an iterative, interactive process, in which they repeatedly need to analyse, improve, update and maintain the timetable, and they find that the tools do not offer sufficient support for this iterative process. In order to address these two issues, this work proposes a knowledge-based approach, in which: (1) constraints can be provided in an expressive and flexible logical language; and (2) different logical inference algorithms can be applied to these constraints in order to provide the different kinds of interactive functionality that the users are missing. As a first step towards developing such a system, we present a logical analysis of the functionality that the end users reported as missing.

2 - A fast threshold acceptance algorithm for solving educational timetabling problems
Nuno Leite, Fernando Melício, Agostinho Rosa

The timetabling problem consists in the scheduling of a set of entities (e.g., lectures, exams, vehicles, or people) to a given set of resources in a limited number of time slots, while satisfying a set of constraints. In this paper, two threshold acceptance based algorithms are proposed for solving educational timetabling problems. The first developed algorithm comprises the basic threshold acceptance. The second one, named FastTA, is a new variation which uses less evaluations at the expense of a relatively small degradation in the solution cost. Two neighbourhood operators were implemented, one that change event rooms, and other that shifts an event to a different period and room. The Kempe chain heuristic is used to correct any infeasibility found. A Saturation Degree heuristic coupled with Conflict Based Statistics is used to construct the initial solutions. The approaches were tested on the public ITC 2007 data set - examination timetabling and course timetabling tracks, attaining competitive results.

3 - Mathematical model and solution approaches for multi-session exams-building assignment
Zeliha Ergul, Zehra Kamisli Ozturk

The educational timetabling problem has been extensively investigated in timetabling literature. However, the problem of assigning exam to examination building has not been studied intensively by researchers. We were inspired by Open and Distance Education System's exams of Anadolu University. Anadolu University Open and Distance Education System which has approximately two millions of students and more than two millions of graduates, is well-known institution in Turkey. In this study, we proposed a multi-objective mathematical model for multisession exam-building assignment problem. This model's objective functions are minimizing distance between student's consecutive session's building, maximizing fill rate of buildings in every session and minimizing variety of booklets for building in every session. Mathematical model has been found inadequate because students-examination building assignment which is belong to Anadolu University Open Education system is a large size real life problem. Starting from this point of view, an order-based multi-objective heuristic algorithm is developed to solve the problem. The obtained solutions by the proposed algorithm are compared with the solution obtained by the mathematical modelling and the out of existing system.

■ HD-13

Thursday, 15:00-16:30 - 207

Copositive and polynomial optimization

Stream: Copositive and conic optimization
Invited session
Chair: *Luis Zuluaga*

1 - Copositive certificates of non-negativity
Luis Zuluaga

Classical certificates of non-negativity for polynomials over semialgebraic sets such as Schmuedgens or Putinars Positivstellensatz are typically written in terms of sums-of-squares polynomials whose degree is not known a priori. Recently, certificates of non-negativity using copositive polynomials of known degree have been proposed in the literature. As a consequence, a very rich class of convergent hierarchies of LMI problems can be constructed to approximate the solution of general polynomial optimization (PO) problems. In this talk we present some interesting theoretical and numerical results regarding these copositive certificates of non-negativity. In particular, we show that they open the door for new uses of both linear and second-order cone based hierarchies to approximate a PO problem.

2 - Quadratic programs with hollows
Boshi Yang, Kurt Anstreicher, Samuel Burer

Let F be a quadratically constrained, possibly nonconvex, bounded set. Let E1, ... , Em denote ellipsoids contained in F with non-intersecting interiors. We prove that minimizing an arbitrary quadratic q over G, the set resulting by deleting the interiors of E1, ..., Em from F, is no more difficult than minimizing q over F in the following sense: if a given semidefinite programming (SDP) relaxation for minimizing q over F is tight, then the addition of m linear constraints derived from E1, ..., Em yields a tight SDP relaxation for minimizing q over G. We also prove results related to the convex hull of the feasible regions in the lifted space. Inspired by these results, we resolve a related question in a seemingly unrelated area, mixed-integer nonconvex quadratic programming.

3 - Complex polynomial optimization
Cédric Josz

Polynomial optimization where variables and data are complex numbers is a non-deterministic polynomial-time hard problem that arises in various applications such as electric power systems, imaging science, signal processing, and quantum mechanics. For enhanced tractability, we transpose to complex numbers the Lasserre hierarchy which aims to solve real polynomial optimization problems to global optimality. We present an algorithm for exploiting sparsity and apply the complex hierarchy to problems with several thousand complex variables. They consist in computing optimal power flows in the European high-voltage transmission network. An algorithm for extracting global solutions will discussed, as well a semidefinite programming solver in complex numbers.

■ HD-14

Thursday, 15:00-16:30 - 305

Hybrid metaheuristics and emerging computational technologies for combinatorial optimization

Stream: Metaheuristics - Matheuristics
Invited session
Chair: *Cesar Rego*
Chair: *Buyang Cao*

1 - Tabu search algorithms for clustering problems - Parallelization and lessons learned
Buyang Cao, Fang Yu, Cesar Rego, Fred Glover

We present variants of Tabu Search (TS) clustering algorithms designed to create more cohesive, connected, and balanced clusters for problems arising in a variety of business applications. In order to deal with large-scale clustering problems, we propose a simple TS variant coupled with a solution strategy that facilitates the parallelization of the algorithm and implement it on the Spark platform. Computational experiments demonstrate our algorithm performs significantly better than the widely-used Spark MLlib K-means algorithm while exhibiting a similar parallel accelerating rate. Our findings open the door to further implementation of meta-heuristics like Tabu Search to solve larger-scale optimization problems on Spark. We also present some lessons learned during the computational experiments: namely, the importance of (a) conducting a thorough data analysis to discover the properties/characteristics embedded in a dataset to set up proper objective functions, (b) identifying appropriate measures for expressing similarities between objects to be clustered and finally (c) a careful vetting process to select suitable decision rules and parameters.

2 - Hybrid genetic algorithms for minimum sum-of-squares clustering
Daniel Gribel, Thibaut Vidal

Clustering plays an important role in data mining, being useful in many fields that deal with exploratory data analysis, such as information retrieval, document extraction, and image segmentation. Among the many existing formulations of clustering problems, the Minimum Sum-of-Squares Clustering (MSSC) problem in the Euclidean space is the most treated one. Yet, although efficient algorithms are essential for data mining applications, most methods used in practice correspond to construction procedures or simple hill climbing. This choice can be related to the large size of practical applications, which often involve several thousands of data points. In this work, we propose a hybrid genetic algorithm for the MSSC which produces high-quality solutions with a well-controlled computational complexity. The method combines a local improvement procedure based on the fast K-means algorithm of Hamerly (2010), with problem-tailored crossover, mutation and diversification operators. This allows to efficiently escape from local minimums and reach high quality solutions. Our computational experiments on classic data sets from the literature with up to several hundred thousand data points demonstrate the high performance of the method, which outperforms previous algorithms in terms of solution quality for a similar computational effort.

3 - A method of handling linear constraints for particle swarm optimization
Kiseok Sung

A method of handling linear constraints for Particle Swarm Optimization (PSO) will be presented. The method is designed to maintain the feasibility of all the particles in the swarm. The particles are represented by the vectors in the real space and move around the real space constrained by the linear constraints. The original PSO did not consider the constraints but the upper and lower bounds of the n-dimensional space the particles move around. This made it hard to consider the relations between the variables in the targeting model. Now POS accepts the constraints and use the penalty and/or repair methods to get the feasibility of particles to the constraints. Those are similar to other metaheuristic methods such as Genetic Algorithm, We present a method to maintain the feasibility of particles while the particles move around the feasible region restricted by the linear constraints. In the method, all the linear constraints of inequality are eliminated so that only the linear constraints of equality are remained to be considered. The proposed PSO method was coded in MATLAB and tested for the sample problems with linear constraints. We present the results of the test.

4 - Extending metaheuristic unconstrained binary quadratic problem solvers to exploit early quantum computers
Michael Booth, Steven P. Reinhardt

Work by Glover et al. over the last decade on metaheuristic solvers has proven the value of exploiting the diverse strengths of different solvers to deliver quickly the best results for unconstrained binary quadratic problems (UBQPs). In this work, we describe extending the metaheuristic notion to incorporate the unusual strengths of early quantum-annealing-based quantum computers (QCs), which quickly find disparate results in rugged energy landscapes. The combination of good seeds from QCs plus refinement by strong solvers running on classical computers is leading to strong results. We describe the current state of algorithms and performance delivered by an open-source hybrid classical/quantum solver.

■ HD-15

Thursday, 15:00-16:30 - 307A

Dynamic models and industrial organisation 1

Stream: Applications of dynamical models
Invited session
Chair: Ladimer Nagurney

1 - A dynamic game theory model for dispute resolution between public and private sector partners in PPPs
Mohammad Rajabi

Public-Private Partnerships (PPPs) is a widely used modality that provides many benefits for the public sector in the delivery of public services. Negotiation is one of the most important business activities in the whole life cycle of PPP projects. The long-term nature of the projects and the rapid changes in the market lead to numerous conflicts between the public sector representative and the private sector partner during the execution stages. In this research, we consider the negotiation process after awarding the contract to the selected private sector partner as a non-cooperative dynamic game of complete information and propose an analytical model to assist with decision making. Our analysis is concerned with resolving economic disputes and provides an appropriate strategy for overcoming financial problems and preventing delays in project's implementation. Managerial guidelines and solutions to prevent conflicts and improve the administrative process are proposed.

2 - A game theory model for freight service provision security investments for high-value cargo
Ladimer Nagurney, Anna Nagurney, Shivani Shukla, Sara Saberi

In this paper, we develop a game theory model in which freight service providers seek to maximize their expected utility by competing for business from shippers and also investing in security. The focus is on high-value cargo, which has been the target of attacks globally. Shippers reflect their preferences for freight service providers through the prices they are willing to pay which depend on quantities shipped and security levels invested in. The Nash Equilibrium is formulated as a variational inequality problem for which existence is guaranteed. Numerical examples illustrate the framework.

3 - An evolutionary game model of bystanders' behaviour
Yuriko Isada, Nobuko Igaki, Aiko Shibata

The bullying has occurred everywhere in society; it is a societal problem that must be solved. We consider a classroom in which bullying is occurring. There are three kinds of students; the bullies, the bullied students and bystanders. Many students turn a blind eye to the bullying because they are afraid that they may become the next target. We focus on the behaviour of bystanders. Each bystander makes a decision to report to the teacher about the bullying or to stay silent by both other bystanders' behaviour and his/her own motivation. Suppose that bullying is resolved when more than the threshold number of students who report the bullying. Bystander makes a decision to report about the bullying to the teacher or to stay silent repeatedly until bullying is resolved. We assume that each bystander makes a decision according to individual satisfactory level instead of completely rational-choice. Bystanders' repeatedly decision making is formulated as an evolutionary game model. Our research shows effective social policy in order to solve bullying problem by using numerical simulations. It is effective to make smaller class size, increase disutility cost and reduce reporting cost and retaliatory cost. Additionally, it is effective that the threshold is reduced.

4 - Biform game models in supply chain analyses
Petr Fiala

A supply chain is a complex and dynamic system of agents, activities, resources, technology and information involved in moving a product or service from suppliers to ultimate customers. Supply chain is defined as a system of suppliers, manufacturers, distributors, retailers and customers where material, financial and information flows connect participants in both directions. Game theory has become a useful instrument in the analysis of supply chains with multiple agents. The ongoing actions in the supply chain are a mix of cooperative and non-cooperative behavior of the participants. The contribution proposes to use biform games for the analysis of supply chains. A biform game is a combination of non-cooperative and cooperative games. It is a two-stage game: in the first stage, players choose their strategies in a non-cooperative way, thus forming the second stage of the game, in which the players cooperate. The biform game approach can be used for modeling general buyer-supplier relationships in supply chains. First, suppliers make initial proposals and take decisions. This stage is analyzed using a non-cooperative game theory approach. Then, suppliers negotiate with buyers. In this stage, a cooperative game theory is applied to characterize the outcome of negotiation among the players over how to distribute the total surplus. Equilibrium search in supply chains is a very important problem. Allocation rules for equilibrium in biform games are proposed.

■ HD-16

Thursday, 15:00-16:30 - 308A

Game theory in supply chains

Stream: Game theory and operations management
Invited session
Chair: *Deng-Feng Li*

1 - Research on two-sided matching model between logistics service suppliers and cross-border e-commerce enterprises
Xiaoxue Zheng

Put forward a two-sided matching model between logistics service suppliers (cross-border platforms) and logistics server demanders (cross-border enterprises) considering logistics service as the main factor. First, this paper introduces logistics service with related to cross-border e-commerce supply chain and analyzed the necessity of two-sided matching. Secondly, the two-sided mutual evaluation index systems of logistics service of cross-border e-commerce supply chain are constructed. Thirdly, due to the uncertainty and fuzzy of cross-border e-commerce market, intervals and linguistic variables are used to represent the evaluation information, and the satisfaction level with respect to each criterion is constructed, then a multi-objective model based on total satisfaction level with respect to two sides is put forward. The example analysis shows the effectiveness and reasonability of the method.

2 - Joint replenishment and transshipment for three locations
Weifen Zhuang

We study the problem of joint replenishment and transshipment for a retailer who sells seasonal products through its three physical stores. The decisions involve the one-shot stocking at the beginning of the season and the supply/transshipment decision throughout the season. Applying a stochastic dynamic programming (DP) formulation to a three-location model with compound Poisson demand processes, we identify the optimal transshipment policy and show that the optimal initial stocking quantities can be obtained via maximizing a concave function. Due to the curse of dimensionality of the DP, we study two downward transshipment models and characterize the optimal polices. To overcome this handicap, we develop upper and lower bounds on the DP value function, which are shown to be asymptotically optimal. We develop effective heuristics by making use of the bound solution. The bounds and heuristics can be extended to deal with the problem of multiple-location.

3 - Cost allocation in collaborative transportation with overlapping coalitions
Ondrej Osicka, Mario Guajardo

Cooperative game theory has increasingly been used in studies of collaborative logistics. A common assumption is the formation of the grand coalition, that is, all players work together and the main focus reduces to a traditional cost allocation problem. An alternative option in coalition formation is a coalition structure, in which the players form a partition, that is, a collection of coalitions where each player belongs to exactly one coalition. We focus on the younger and more general concept of coalition configuration, which extends the coalition structures by allowing overlapping coalitions. We study cost allocation and stability concepts in coalition configuration, specifically focused in the transportation problem. In this problem, a set of demand points must be served by supply points at minimum cost. A coalition configuration turns useful in this context, because in practice collaborative transportation usually involves just a few partners and the geographic location of the points may naturally provide a player with opportunities for collaboration in several different coalitions.

■ HD-17

Thursday, 15:00-16:30 - 309A

Distributed stochastic optimization and information processing

Stream: Nonlinear optimization with uncertainties
Invited session
Chair: *Dusan Jakovetic*
Chair: *Dragana Bajovic*

1 - Mitigating the complexity of fictitious play in large games: A stochastic approximation approach
Brian Swenson, Soummya Kar, Xavier João

Fictitious play (FP) is a classical algorithm for learning equilibria in multi-agent games. The algorithm has diverse applications ranging from learning optimal strategies in poker to large-scale optimization and dynamic programming. Despite theoretic convergence guarantees, the computational requirements of FP make it extremely impractical to deploy in large-scale settings. Using stochastic approximation techniques, we develop a variant of FP–termed, "Single Sample FP" (SSFP)–that reduces the per-iteration complexity from exponential down to linear in terms of the number of players.

2 - Accelerated consensus over stochastic networks through distributed filter design
Stephen Kruzick, Jose Moura

Coordination of multi-agent network systems often requires that node-agents reach agreement on node data statistics while only engaging in local communications, a problem known as distributed consensus. In distributed average consensus, the nodes implement linear dynamics with state that approaches the data mean, a task with utility in applications such as processor load balancing and sensor data fusion. Filters that incorporate previous consensus estimates can significantly improve the convergence rate, leading to accurate results in fewer iterations. Our work focuses on optimal design of acceleration filter coefficients for networks described by stochastic processes. For fixed random networks, intuition from graph signal processing implies that spectral statistics of random graph matrices govern optimal filter design. For networks described by graph stochastic processes, the connection to graph matrix spectral properties becomes less tractable. We first propose and evaluate filter optimization criteria based on analytically calculated deterministic equivalents for graph matrix empirical spectral distributions of large-scale fixed random networks. Subsequently, we describe a distributed filter design algorithm for networks described by stationary graph stochastic processes based on a self-accelerating consensus process. Importantly, this method allows us to deal with potentially large random network models that are stationary but otherwise unknown in distribution.

3 - Distributed composite hypothesis testing: A consensus+innovations approach
Anit Kumar Sahu, Soummya Kar

In this work, we study recursive composite hypothesis testing in a network of sparsely connected agents. The network objective is to test a simple null hypothesis against a composite alternative concerning the state of the field, modeled as a vector of (continuous) unknown parameters determining the parametric family of probability measures induced on the agents' observation spaces under the hypotheses. Specifically, under the alternative hypothesis, each agent sequentially observes an independent and identically distributed time-series consisting of a (nonlinear) function of the true but unknown parameter corrupted by Gaussian noise, whereas, under the null, they obtain noise only. A distributed recursive generalized likelihood ratio test type algorithm of the consensus+innovations form is proposed, in which the agents estimate the underlying parameter and in parallel also update their test decision statistics by simultaneously processing the latest local sensed information and information obtained from neighboring agents. Under a global observability condition, algorithm parameters which ensure asymptotically decaying probabilities of errors are characterized and upper bounds on large deviations decay exponent for the error probabilities are obtained.

4 - Distributed Newton-like methods with variable number of working nodes
Dusan Jakovetic, Natasa Krejic, Natasa Krklec Jerinkić, Dragana Bajovic

Recently, an idling mechanism has been introduced in the context of distributed first order methods for minimization of a sum of nodes' local convex costs over a generic, connected network. The idling mechanism operates in such a way that an increasing number of nodes becomes involved in the algorithm (on average) as the iteration counter k grows, thus avoiding unnecessarily expensive exact updates at the initial iterations while performing beneficial close-to-exact updates near the solution. Here, we present a methodology that demonstrates how idling can be successfully incorporated in distributed second order methods also. Interestingly, a second order method with idling exhibits very similar theoretical convergence and convergence rates properties as the corresponding standard method (without idling), but with significantly cheaper updates. This usually results in significant communication and computational savings of the idling-based method.

■ HD-18

Thursday, 15:00-16:30 - 2101

Continuous multiobjective optimization and applications

Stream: Multiobjective optimization
Invited session
Chair: *Christiane Tammer*
Chair: *Petra Weidner*

1 - Necessary optimality conditions for some nonconvex facility location problems
Marcus Hillmann

The problem of locating a new facility with simultaneous consideration of existing attraction and repulsion points is a problem with great practical relevance, e.g., in the fields of economy, city planning or industrial design. Unfortunately, the consideration of negative weights makes this problem in general a nonconvex one, so that none of the established algorithms for location problems are able to solve it. We will therefore present a new approach to derive necessary optimality conditions for such problems using the nonconvex subdifferentials by Ioffe and Kruger/Mordukhovich. While there are many strong theoretical results on these subdifferentials, it is rarely possible to explicitly calculate them or use them for applications. After giving a brief review on definition, properties and calculus of the mentioned subdifferentials we will show, that for certain distance functions it is possible to precisely calculate the corresponding subdifferentials. By taking advantage of the special structure of the problems we will then derive necessary optimality conditions for some instances of semi-obnoxious facility location problems and discuss them. At the end of the talk, we will give an outlook on open questions and possible future developments.

2 - Decision making with variable domination structures and vector optimization
Petra Weidner

Decision making problems can be described in different ways. The emphasis can be placed on elements that dominate others or on those that are dominated. For both types, possibilities are shown to find optimal decisions by vector optimization problems. Properties of the solution sets of these general vector optimization problems are given and possibilities to determine the solutions by scalar optimization problems are presented.

3 - Optimality conditions in generalized-convex constrained multi-objective optimization
Christian Günther

This talk is devoted to the study of general multi-objective optimization problems involving a vector-valued objective function, that is componentwise generalized-convex (e.g., semi-strictly quasi-convex, quasi-convex, or pseudo-convex), and certain constraints. Using some recently derived relationships between constrained and unconstrained multi-objective optimization (see Günther and Tammer 2016 & 2017), we present new optimality conditions for certain classes of generalized-convex (possibly nonsmooth) constrained multi-objective optimization problems. Furthermore, we apply our approach to problems where the constraints are given by an inequality system with a finite number of constraint functions. Under certain constraint qualifications (e.g., the well-known Slater constraint qualification) we derive new optimality conditions for such problems.

■ HD-19

Thursday, 15:00-16:30 - 2102AB

Empirical studies in airline operations

Stream: Data driven modeling in operations management
Invited session
Chair: *Jiyin Liu*
Chair: *Soheil Sibdari*

1 - A constraint programming approach for the airport gate assignment problem considering regular and disrupted operations
Daniel Guimarans

The Gate Assignment Problem (GAP) is one of the most important problems airport operators face on a daily basis. The problem consists of assigning every flight (aircraft) to an available gate, while maximising operational efficiency at the airport and passengers' convenience. Most research done on the GAP generally does so by minimising the walking distance for passengers, maximising gate occupancy, ensuring enough slack between consecutive flights, etc. However, this planning does not consider common operational disruptions involving flight delays, cancellations, or temporarily unavailable gates. We present a Constraint Programming formulation for the GAP, which combined with a branch-and-bound algorithm is able to schedule gates during regular operations and also repair a plan in case of disruptions. We define the problem as multi-objective, minimising: (i) the passengers' walking distance; (ii) the distance travelled by connecting bags on airside; and, (iii) the number of gate changes in disrupted situations. The formulation flexibility allows for introducing new objectives (e.g. reducing infrastructure stress in areas of the terminal) without modifying the search algorithm. We assess our model on scenarios derived from real operations at Barcelona airport.

2 - A disjunctive approach to solve the hub management optimization problem
Gianmaria Leo, Joshua Hirschheimer, Mauro Piacentini

As the demand for air travel continues to grow, the existing airport infrastructures are being impacted by congestion and delays. Successful airlines have been stretching decision-making processes revising the focus on operations to reduce the costs arising from negative customer experience from disrupted journeys. Airlines can deliver the total travel experience by closely managing the resources that facilitate connections and on-time departures in their hub. These resources can be employees, ground equipment, or infrastructure such as gates. We introduce an original holistic approach to improve airport operations, solving a new optimization problem: the Hub Management Problem (HMP). HMP optimizes local and downstream connections by reallocating gates, stands and ground staff, and rescheduling flights departure and turnaround activities. The model accounts for hub controls relations, resources availability, time dependencies and operational rules. We formulate HMP as Job-Shop Problem and provide an exact method based on disjunctive graph concept. While the HMP turns out to be strongly NP-hard, we investigate a polynomial separation oracle making our method cost-effective in practice, and scalable over time horizon, resource conflicts and operational constraints. We present a case study for a major airline hub airport in the Middle East. The airport has 480 aircraft movements per day, serving an average of 68,000 passengers, 70% of whom are transiting there.

3 - Heuristic solutions to the flexible airport gate assignment problem
Jiyin Liu, Shuo Liu, Wen-Hua Chen

We develop a mixed integer linear programming model for the airport gate assignment problem that allows flexibility in the assignment of different types of aircraft to different gates so as to minimise the number of aircraft assigned to remote stands. All the usual constraints are considered to ensure feasibility and safety. Penalties are introduced to encourage exact match between aircraft and gate types. Test on small problems show that allowing flexibility can increase gate utilisation. However, it takes very long time to solve the model for large problem instances. We propose heuristic methods to decompose the model into smaller ones which can be solve quickly. The decompositions are according to aircraft type and arrival time. Computational tests are carried out to evaluate and compare the performance of the heuristic methods. The methods are also tested in situations with uncertainties in aircraft arrival times, i.e., the aircraft may arrive earlier or later than scheduled.

4 - Airfare dynamics in the U.S. market: A big data analytics of competitiveness
Soheil Sibdari, Farbod Farhadi

During the past few decades total passenger demand in domestic and international air travel have been constantly increasing significantly. Passengers on all scheduled U.S.-based flights, Domestic and International, have rose from 700 million in 2003 to almost 900 million passengers in 2015, according to U.S. Department of Transportation's Bureau of Transportation Statistics (BTS). In contrast, airlines have been merging in the past two decades in the US market and as a result, most of domestic air travel is being operated only by four major carriers. In this study, we address the dynamics of airline competition and air fares in US markets, in presence of verity of direct and indirect contributing factors such as airline capacity decisions, operating expenses, and status of economy.

■ HD-20

Thursday, 15:00-16:30 - 2103

Dynamical models in sustainable development 2

Stream: Dynamical models in sustainable development
Invited session

Chair: *Beatriz Beyer*
Chair: *Beatriz Beyer*

1 - DEA model with future performance for regional eco-efficiency analysis
Wendi Ouyang, Jian-Bo Yang

Decision-making for selecting a set of sound sustainable policies has become a top issue. In the recent years, eco-efficiency analysis has been regarded as an important way to assist policymakers to address this issue. However, policymakers are no longer satisfied with only understanding the sectional eco-efficiency of a region. The utility of policy is continuous and dynamic, but existing eco-efficiency analysis only provides static efficiency results. As such, policymakers are not supported to understand long-term policy effects and this results in short-sighted decision-making. Such eco-efficiency analysis limits its original intention to be used as a tool for sustainable development. Introducing long-term perspectives into eco-efficiency analysis is a requirement of policymakers. This study will consider future performance into eco-efficiency analysis to replace traditional static eco-efficiency analysis. Data envelopment analysis (DEA) will be updated to a new model for long term eco-efficiency analysis based on time series or system dynamics.

2 - The joint impact of environmental awareness and system infrastructure on e-waste collection
Wenyi Chen, Jianmai Shi, Vedat Verter

The prevailing literature on the design of reverse logistics networks for e-waste collection does not consider the impact of a consumer's environmental awareness on his propensity to return an end-of-use item. In this paper, we study the impact of simultaneously determining the optimal density of a network of collection centers as well as the most appropriate level of investment in the public's environmental awareness. We present a dynamic model for the joint design of the network infrastructure and the public campaign intensity. In particular, we adopt a Nerlove-Arrow advertising model to capture the potential influence of public awareness campaigns in increasing the consumers' environmental sensitivity over time. A case study is presented based on the operations of the Canadian E-Waste Stewardship Program in the Greater Vancouver region. We find that investments into environmental awareness can enable the take-back scheme to improve its collection rates significantly. Our findings through the case study also reveal that running an advance campaign prior to the launch of the collection network can be an effective strategy in most cases. We also present an extended model, which highlights that increasing the investment in environmental awareness can be utilized as a lever to offset the impact of increased hauling costs.

3 - Agent-based simulation of a heating market
Beatriz Beyer, Jutta Geldermann, Lars-Peter Lauven

Heating and cooling for buildings and industries account for 50% of the annual energy consumption in the European Union. In Germany the heating market causes 40% of all energy related greenhouse gas emissions. The use of biomass for heating purposes, especially wood, plays an important role in reducing these emissions. In the EU-project BIOTEAM, project partners from six different countries analyzed the sustainability of biomass-to-energy pathways as well as the relevant legislation. A common finding was a disparity between legislative intentions and impacts. Qualitative tools had been used to offer advice on beneficial regulations, providing only a static overview of the market structure. In order to obtain deeper insights on the market dynamics for a more sustainable heating market we have developed a Multi-Agent-System. In this bottom-up approach, a selected long term heating market, combined with a wood market, are simulated, while considering both behavioral aspects and governmental regulations. The various households and their dissimilar decision behavior for a heating system as well as other market actors are represented by different agents. Assorted scenarios concerning prices, behavioral changes and regulations are simulated. This agent-based model is able to resemble reality more closely and can therefore provide a deeper understanding of the heating market. Moreover it could be used as a decision support system and be adapted to different regions.

■ HD-21

Thursday, 15:00-16:30 - 2104A

Cutting and Packing 4

Stream: Cutting and packing
Invited session

Chair: *Ramon Alvarez-Valdes*

1 - Approximate packing of circular-like objects in a rectangular container
Rafael Torres, Antonio Marmolejo, Igor Litvinchev, Daniel Mosquera, Edith Lucero Ozuna Espinosa

The problem of packing a limited number of unequal circular objects in a fixed size rectangular container is considered. A circle is considered as a set of points that are all the same distance (not necessary Euclidean) from a given point. Different shapes, such as ellipses, rhombuses, rectangles, octagons, etc. can be treated similarly by simply changing the definition of the norm used to define the distance. The aim is to maximize the (weighted) number of objects placed into the container or minimize the waste. Using a regular grid to approximate a container, packing is reduced to assigning objects to the nodes of the grid subject to non-overlapping constraints. The packing problem is then stated as a large scale linear 0-1 optimization problem. Recursive packing allowing nesting circles inside one another is also considered. Numerical results are presented to demonstrate the efficiency of the proposed approach.

2 - A hybrid metaheuristic approach for the two-dimensional loading vehicle routing problem with heterogeneous fleet
David Álvarez Martínez, Luis Miguel Escobar Falcón, John Willmer Escobar

In this work, we present a hybrid metaheuristic approach for the 2L-HFVRP with sequential loading constraints. This problem combines two well-known NP-hard problems: the heterogeneous fleet vehicle routing problem (HFVRP) and the two-dimensional sequential loading problem (2D-LP). The proposed approach for the considered problem uses a set of initial solutions generated by a specialized constructive algorithm; trying to get an initial population based on a set of good solution for a TSP problem. A Genetic Algorithm (GA) was developed to manage all the search process. To encoding each chromosome is used the Prins' auxiliary graph. Meanwhile, the feasibility of the solutions respect to the loading constraints is checked by a reactive GRASP algorithm. The GRASP verifies if the demand of the customers belonging to a route must be placed in the fleet by considering sequential loading constraints (multi-drop constraints). Five different crossover methods SJX, PMX, OX, CX, and OBX were implemented. In this case, after applied the crossover methods the algorithm checks the packing feasibility of the new offspring. The best individuals could be mutated with a randomized shaking procedure. Therefore, the population is updated if better solutions are found. Finally, the proposed approach shows good quality results on benchmarking instances, improving some of the best-known previous solutions.

3 - Studying different models for truck loading process
Maria Teresa Alonso Martínez, Ramon Alvarez-Valdes, Manuel Iori, Francisco Parreño

This paper deals with the problem of a distribution company that has to serve its customers by putting first the products on pallets and then loading the pallets onto trucks. We approach the problem by developing and solving integer linear models, considering three types of practical constraints. Geometric constraints where pallets are completely inside the trucks, weight constraints where the weight, that can bear, is limited by the axle and the position of the centre of gravity and stability constraints for avoiding movements during the journey. Also, it is dealt with the model where demand have to be served over a set of periods. Studying two alternatives. The models have been tested on a large set of real instances involving up to 46 trucks and kindly provided to us by a distribution. In most cases the optimal solution is achieved in short running times. Moreover, when optimality cannot be proven, the gap is usually very small, so high quality solutions are obtained for all the instances tested.

■ HD-22

Thursday, 15:00-16:30 - 2104B

Routing and reliability problems

Stream: Discrete optimization, mixed integer programming (contributed)
Contributed session
Chair: *Yousef Maknoon*
Chair: *Tonguc Ünlüyurt*

1 - Planning of feeding station installment for a full electric large capacity urban bus system
Virginie Lurkin, Yousef Maknoon, Shadi Sharif Azadeh, Michel Bierlaire

During the last few decades, environmental impact of the fossil fuel-based transportation infrastructure has led to renewed interest in electric transportation infrastructure, especially in urban public mass-transportation sector. The deployment of battery-powered electric bus systems within the public transportation sector plays an important role to increase energy efficiency and to abate emissions. Rising attention is given to bus systems using fast charging technology. An efficient feeding stations installation and an appropriate dimensioning of battery capacity are crucial to minimize the total cost of ownership for the citywide bus transportation network and to enable an energetically feasible bus operation. The complexity of the problem comes from the simultaneous decisions of the power capacity for the batteries in the buses, and the locations and types of feeding stations. A mixed-integer linear optimization model is developed to determine the cost optimal feeding stations installation for a bus network as well as the adequate battery capacity for each bus line of the network.

Planning of feeding station installment for electric

2 - Formulation for the asymmetric traveling salesman problem using mixed integer programming
Gabriel Solari Carbajal

The Traveling Salesman Problem (TSP) is a very important combinatorial optimization problem and its study is not yet complete. The Asymmetric Traveling Salesman Problem (ATSP) is the version where the cost of going from city i to city j is different to the cost of going from city j to city i. Exact solutions, heuristics and metaheuristics have been developed. In the relation for the formulation of the Assignment Problem (AP) and the ATSP, using binary variables, it is necessary to eliminate the occurrence of subtours. In the present investigation for ATSP formulation has been developed using Mixed Integer Programming. For this we have added an integer variable to the traditional formulation for the AP, which indicates the position of each city in the sequence. The relationships between the binary variable and the integer variable are obtained, eliminating the subtour. The proposed formulation has been used to solve smaller problems using commercial software and the optimum solution has been reached in all cases. The results obtained give us the idea that the present formulation is very promising.

3 - Branch-and-Benders-cut algorithm for the network repair crew scheduling and routing problem
Alfredo Moreno, Pedro Munari, Douglas Alem

Extreme events as disasters cause partial or total disruption of basic services such as water, energy, communication and transportation. The road restoration problem in post-disaster situations is particularly important to perform evacuation of the victims and distribution of emergency commodities to relief centers or affected areas. It involves crew scheduling and routing decisions that make the problem too complicated to be effectively solved for practical instances using Mixed Integer Programming (MIP) formulations. We propose a Benders-based branch-and-cut method, also called Branch-and-Benders-Cut (BBC) method, for the Network Repair Crew Scheduling and Routing Problem. The analysis of results shows that the proposed exact method improves the results of the MIP formulation and state-of-the-art exact and meta-heuristic methods proposed in literature. Computational experiments using real-life data obtained from a disaster in a region of Rio de Janeiro (Brazil) indicate that the proposed BBC algorithm can be effective in practice.

4 - Fault localization for series systems when tests are unreliable
Tonguc Ünlüyurt, Zahed Shahmoradi

In this study, we consider a failed series system in which any of the components of the system can be the cause of the failure with different probabilities. We are allowed to sequentially test the components in the system to localize the faulty one. Prior probability that a component is the cause of the failure as well as the cost of testing a component are known. We consider unreliable tests that can identify a component as working when in reality it is down, and vice versa. Therefore, there are costs corresponding to misclassification of the components in the system and the total expected cost becomes the sum of inspection costs and misclassification costs. In this study we propose a model in which the repetition of tests are allowed at most once after a positive result. Therefore, the aim here is not only to determine the best test sequence, but also the best repetition strategy with minimum expected cost. The mathematical model is introduced and analyzed. Numerical results are presented to demonstrate the possible cost reductions through repetition of the tests.

■ HD-23

Thursday, 15:00-16:30 - 2105

Timetabling and rescheduling

Stream: Optimization for public transport
Invited session
Chair: Ángel Marín

1 - Timetabling with integrated passenger distribution
Johann Hartleb, Marie Schmidt, Markus Friedrich

One important objective in timetabling is optimizing the quality of a timetable as perceived by the passengers. While most state-of-the-art timetabling optimization models assume that the route choice of the passengers is an input to timetabling and thus optimize travel time on pre-specified routes, we assume that passengers are distributed among a set of routes based on the timetable, and thus integrate timetabling and route choice in our model. Three different models for the objective 'perceived quality' can be formulated: average (generalized) travel time on travel time minimal paths, average (generalized) travel time as predicted by transit assignment models, and logsums, a common measure in discrete choice modelling to describe the overall utility of all useful paths. We discuss the underlying assumptions on passenger behavior and perception, give mathematical programming formulations, and compare the results on a small example.

2 - The passenger-centric train timetabling problem: A Stackelberg equilibrium game
Ricardo Garcia-Rodenas, Maria Luz Lopez

This communication formulates a passenger-centric timetabling problem as a Stackelberg equilibrium game. At the upper level of the problem the decision maker (leader) establishes the train timetables and at the lower level the passengers (followers) choose the train to make their trip. This study proposes a generalized nested logit model to represent the lower level problem. Their main features are: i) the discrete-choice model uses radial basis functions to define non-linear utilities, ii) it allows correlations between the alternatives to be addressed and thus it considers the competition between trains as a function of their features, and iii) it introduces the capacity constraints of the trains into the decision process of the passengers. The passengers compete for the capacity of the trains. The upper-level problem takes into account the decision maker's point of view. The resulting bilevel model exhibits a complex structure which requires metaheuristics as a solution method.

3 - Integrate macro-micro real-time railway traffic management
Ángel Marín, Luis Cadarso, Ricardo Garcia-Rodenas, Paola Pellegrini, Joaquin Rodriguez

Optimization models for real-time railway traffic management tackle the problem of determining actions to reduce the effect of disturbances in railway systems. Mainly two research streams can be identified: train routing and scheduling using microscopic models are designed to include all the feasibility constraints, avoiding the train conflicts, under the point of view of the infrastructure managers. On the other hand, delay management is studied in the macroscopic models focus on the impact of routing and scheduling decisions on the quality of service perceived by the passengers, under the point of view of the railway managers. Both approaches micro-macro are integrated in the context of decomposition methods. Some computational tests have been studied with concrete rail applications.

■ HD-24

Thursday, 15:00-16:30 - 301A

Internet of things in healthcare

Stream: CORS SIG on healthcare
Invited session
Chair: Michael Carter
Chair: Andrew Leung

1 - Quantifying the impact of 'Internet of Healthcare Things (IoHT)': Addressing domains of care quality
Tahera Yesmin, Michael Carter

Internet of healthcare things (IoHT): an emerging technology allows different machines and equipment to relay data to each other with the help of embedded sensors. Effective usage of data generated from these connected equipment can substantially change the mode of care delivery and can therefore leverage the improvement in quality of care provided. Many researchers have exhibited the working methodology and applications of Internet of things in healthcare in various aspects of patient care. However, very few researches have evaluated the outcomes of it. This research demonstrates the effects of using IoHT in one of the hospitals of Ontario, Canada; which has implemented smart beds, smart hand hygiene support system, smart RFID badges, dome light indicators and smart calling system in one of their units. With the help of various tools of data mining, statistics and industrial engineering this study measures the impact of IoHT in different domains of quality of care specifically patient safety, effectiveness, efficiency and timeliness. This study also addresses the staff experiences in handling these new technologies. The findings from this research thus indicate the effectiveness of the intervention and hence hold the potential for decision making in improvement of care quality.

2 - Mackenzie health: An analysis of a "smart" Internet of Things approach to healthcare
Chris Stewart

Providing high direct care times and quick responses to patient calls is part of quality patient care, but doing so in a busy hospital unit is challenging; nurses typically have multiple patients, documentation and many other duties preventing them from immediately attending to patients. Timely responses to patient calls can have a positive impact on direct care times, falls risk and overall patient satisfaction. The emerging Internet of Things (IOT) offers the potential to dramatically improve communication and efficiency by building data collection and decision making intelligence into everyday devices. Mackenzie Health Hospital is piloting an IOT approach to healthcare in one of their general medicine wards with the creation of an "innovation unit". This unit is equipped with various networked "smart" technologies including: nurse RFID badges for location tracking, mobile smartphone devices, and "smart" beds with built-in sensors and call button system. Through data mining and simulation modelling of the ward and "smart" system, we assess the level of improvement that these new technologies provide, as well as explore alternative strategies for how they can be further leveraged to improve response times, efficiency and care quality in the unit.

3 - Quantitative analysis of volume and scan time impact with dedicated ambulatory site in medical imaging
Andrew Leung

The demand for diagnostic imaging is high, causing wait time problems as hospitals manage the demands from their patient populations. The majority of the scans are low priority and are referred from community physicians or specialists. Additional scheduling complexity comes from the variation in the protocols determined by radiologists, which are recorded as free text. The Joint Department of Medical Imaging (JDMI) at University Health Network (UHN) plans to transform one of its sites into a dedicated ambulatory site where all low priority community referred scans will be directed. This analysis quantifies the impact of dedicating a hospital as an ambulatory site in a cluster of hospitals in terms of scan time and patient volume. The grouping of the protocols is done using natural language processing and a nearest neighbour approach. A simple greedy trade algorithm is developed that shifts patient to and from the ambulatory site based on protocol type and scan time.

■ HD-25

Thursday, 15:00-16:30 - 301B

OR application in forest resources management

Stream: CORS SIG on forestry
Invited session
Chair: *Marc-André Carle*

1 - Studying the impact of harvest volume uncertainty on optimal policies: Comparison between Monte Carlo simulation and stochastic programming
Jules Comeau

This study explores yield uncertainty in harvesting operations as it pertains to the impact it has on the robustness of optimal policies. More specifically, we are interested in comparing results from a stochastic programming optimization with results from Monte Carlo simulation to get a better understanding of the impact of stand-level harvest-time yield uncertainty.

2 - Aligning forest management and industrial demand using a large-scale linear programming model
Corinne MacDonald, Evelyn Richards, Eldon Gunn

We present a linear programming model that optimizes long term forest planning through assignment of silvicultural prescriptions to stands, shipments of timber products from the forest to mills, and transshipments of sawmill residues to pulp mills and bio-refineries. We show how this model can be used to assess the impact of forest management decisions on the forest industry and the impact of forest industry decisions on forest management. Working closely with the Nova Scotia Department of Natural Resources, we have developed a case-study of the province's entire forest, an area of over 4 million hectares, represented in our model by more than 700,000 stands. The Nova Scotian forest industry with 9 saw mills, 2 pulp mills, 2 export markets, and 2 bio-refineries is included. We present several scenarios that demonstrate analysis of important strategic policies, including assessing the cost to industry of forest ecosystem constraints, evaluating the potential for increasing capacity in the local industry, and impacts of mill closures.

3 - A new model for spatial harvest planning including adjacency
Marc-André Carle, Chourouk Gharbi

Forest management rules are limiting allowable harvest size and restricting cut on adjacent area for a fixed period. This is commonly named adjacency constraint. There are two main approaches to address adjacency in harvest scheduling modeling; unit restriction model (URM) and area restriction model (ARM). Methodologies to solve URM are relatively simple and based on defining contiguous groups of planning units, each satisfying the maximum opening size. Models that allow simultaneous harvesting of adjacent planning units while their combined area does not exceed the maximum cut size are ARM. Theoretically, ARM are more flexible and should generate harvesting plans with higher values than URM. Many integer programming and mixed integer programming approaches have been proposed to model this combinatorial problem. Researchers have used exact methods and metaheuristics to solve it. Experiences have shown that exact methods could provide optimal or near optimal solutions within reasonable computing time. However, their application is still limited to small and medium problems. Therefore, modeling and solving large problems of spatial forest planning still represent a challenge. In this paper, we present a new integer programming formulation based on ARM approach. An exact method is used to solve it. We describe and analyse our approach and compare it with formulations proposed in the literature. Analysis is illustrated by the use of four North American forests.

■ HD-26

Thursday, 15:00-16:30 - 302A

OR in agriculture 1

Stream: OR in agriculture
Invited session
Chair: *Concepcion Maroto*

1 - An aggregate linear programming model to estimate the pollutant and greenhouse gases emissions from livestock
Concepcion Maroto, Marina Segura, Concepción Ginestar, Baldomero Segura

The European Union has commitments to reduce greenhouse gases (GHG) and pollutant emissions under different protocols and directives. States are required to draw up programmes for the progressive reduction of their emissions, livestock being the source of 10% of the total. Countries can mitigate these emissions by improving animal production management, in particular through nutrition, housing and waste management. Nevertheless, there is little research on how to decrease GHG and pollutants by modifying animal diets. National inventories of livestock emissions mainly use methods based on manure management, even though the influence of animal diets is well known. As feed intake is an important variable in predicting emissions, which depend on animal nutrition (energy, gross protein, fibre...), the objective of this research is to design and explore the potential contributions of linear programming models to improving the quality and accuracy of measurement of livestock emissions at country level. Firstly, we have developed a linear programming model with which we can estimate the most important emission factors attributable to diet in intensive animal production. Secondly, this model has been applied to Spanish livestock analysing the solution sensitivity to the model coefficients.

2 - Modeling of a new hybrid feeding system in pig industry
Émilie Joannopoulos, François Dubeau, Jean-Pierre Dussault, Mounir Haddou, Candido Pomar

Feed represents more than 70% of the production cost in the pig industry and the current economic context leads us to reduce it. In this presentation we will state several feeding systems. Firstly, we will present the traditional linear model which is currently used in the industry. Secondly, a feeding system using two feeds will then be introduced. In this model, pigs are fed with two feeds that are blended in different proportions each day in order to satisfy the daily requirements. We get a bilinear model which is much harder to solve compared to the traditional one. Finally, we will present a new hybrid method: a mix between the traditional feeding system and the one using feeds. The idea is to partition the growth period in phases and in each phase, a feeding system using two feeds is used. Besides, two consecutive phases use a common feed. The associated model is again a bilinear one. All these models were studied as a monocriterion problem (minimizing feed cost) and as a multicriteria problem (minimizing feed cost and phosphorus and nitrogen excretions). We will see that with these methods we can not only decrease the feed cost but also decrease the phosphorus and nitrogen excretions.

■ HD-27

Thursday, 15:00-16:30 - 302B

Optimization in renewable energy systems 2

Stream: Optimization in renewable energy systems
Invited session
Chair: *Jesse O'Hanley*
Chair: *Gerhard-Wilhelm Weber*

1 - A hybrid stochastic dynamic programming - Tabu search approach for long-term energy planning
Yves Mbeutcha, Michel Gendreau, Grégory Emiel
In its long-term hydro generation planning, Hydro-Quebec needs to evaluate the impact of additional firm load contracts on the energy reliability of the system and the future revenues for the next fifteen years. Those criteria are mainly threatened by the uncertainty of future inflows especially in a context of climatic change and inter annual persistence. The threat is managed with the energy surplus exchange policies of the company on foreign spot markets. Policies obtained by classical Stochastic dynamic programming failed to represent adequately the risk brought by some inflows hypothesis on the system reliability. We present a Tabu Search approach to correct an initial policy in order to improve its performance with different hypothesis regarding the underlying stochastic process.

2 - MIP models for optimizing jacket foundations for offshore wind turbines
Martina Fischetti
Modern wind turbines are getting still bigger and more remotely located. One of the drivers is higher wind speeds at offshore sites and less visual/noise impact. Having big turbines in deep sea areas, nevertheless, often requires higher foundation costs. Today, the most used foundation type is the monopole. Monopiles are relatively easy to install and less expensive. Nevertheless, at deeper waters or complex soil conditions, jacket foundations are needed. Consequently, many developers are now looking at jacket foundations and ways of reducing their complexity and cost. In this work we aim at reducing jacket foundation costs by optimizing their design. A close collaboration with a European leading company in wind farm design, allowed us to have a close look at the problem and its constraints. Company experts provided us with a detailed plan for the jacket structure, and a set of feasible tubes for each joint-to-joint connection. We are asked to select the best tube type for each connection, in order to minimize the total mass (i.e. the total cost) while satisfying all fatigue constraints. Choosing the jacket tubes from a discrete set, instead of designing them for each specific jacket, opens up for mass production, and therefore imply a further reduction of costs. We formulate the problem as a Mixed Integer Linear Programming model, and present preliminary results for various real-life jacket structures.

3 - Optimal location of small hydropower dams: Balancing renewable energy gains and river connectivity impacts
Jesse O'Hanley, Christina Ioannidou

We address the problem of locating small hydropower dams in an environmentally friendly manner. We propose the use of a multi-objective optimization model to maximize total hydropower production, while limiting negative impacts on river connectivity. Critically, we consider the so called "backwater effects" that dams have on power generation at nearby upstream sites via changes in water surface profiles. We further account for the likelihood that migratory fish and other aquatic species can successfully pass hydropower dams and other artificial/natural barriers and how this is influenced by backwater effects. Although naturally represented in nonlinear form, we manage through a series of linearization steps to formulate a mixed integer linear programing model. We illustrate the utility of our proposed framework using a case study from England and Wales. Interestingly, we show that for England and Wales, a region heavily impacted by a large number of existing river barriers, that installation of small hydropower dams fitted with even moderately effective fish passes can, in fact, create a win-win situation that results in increased hydropower and improved river connectivity.

■ HD-28

Thursday, 15:00-16:30 - 303A

Applications of OR 4

Stream: Applications of OR (contributed)
Contributed session
Chair: *Narasimhan Ravichandran*

1 - Combinatorial auction mechanism for allocation of transportation in collaborative networks
Daniel Nicola

In this work, a combinatorial auction-based mechanism is applied to a collaborative transportation network, in which carriers interchange requests in order to increase efficiency. All carriers operate in a hub-and-spoke network consisting of two clusters, where short-haul vehicles cover intra-cluster routes and larger capacity long-haul vehicles are used for the inter-cluster routes. Transport requests are reallocated between carriers via an auction organized by a central, neutral institution. The mechanism is composed by four major processes: Request Selection, Bundle Generation, Bid Generation and Winner Determination. Bidders select which requests to send to the auctioneer. The auctioneer groups complementary requests into attractive bundles to be offered to all the carriers in the network. Carriers then bid on each of these bundles, and finally, the auctioneer solves the Winner Determination problem by assigning bundles to carriers minimizing the total cost to be paid. Calculating exact costs for each bundle would involve prohibitive computational costs of solving a large number of VRP's. We therefore propose a regression-based approximation for bundle evaluation. It is shown, that by using the proposed methods for every process, it is possible to run combinatorial auctions of a real-world size. Moreover, this mechanism allows the network to improve efficiency by reducing total distance traveled by up to about 25% , in relatively small computing times.

2 - Chinese postman problem approach for waste collection operations in the city of Erzurum in Turkey
Mustafa Yilmaz, Merve Kayacı Çodur, Erdem Aksakal

Many practical arc routing problems involve finding paths or tours that traverse a set of arcs in a graph. The aim of solving such problems is to determine a least cost tour which covers all or subset of arcs in a graph with or without constraints. The Rural Postman Problem (RPP) is one of the most central problem in arc routing. In a daily life, RPP is applied many practices like delivering, road maintenance, electric meters reading, security patrols travelling and snow plowing operations to determine optimum vehicle routes. Waste collection operations also can be modeled as a RPP. The wastes are in small containers located almost continuously along streets in the centres of the cities. In this study, The RPP approach has been addressed and the mathematical formulation is used for determining optimum route of waste collection vehicle that travelling the streets for collection garbages in the city of Erzurum in Turkey. The model is conducted on the networks which have been created for different areas of the city of Erzurum and the results are given.

3 - Efficient anomaly detection using unsupervised cooperative machine learning
Rasha Kashef

A variety of techniques have been developed to detect outliers in several research applications. More recently, the applications of anomaly detection methods have seen a proliferation in business intelligence where industries such as healthcare estimate fraudulent cases, abuse, and waste. In addition, social media has dawned a new age of available information where geolocated data per Instagram has allocated methods for outlier detection in practice for the early detection of unusual events in urban areas. Current approaches for detecting outliers using clustering techniques explore the relation of an outlier to the clusters in data. We present a novel clustering-based outlier detection algorithm (CCOD) that uses the notion of cooperative clustering towards better detection of outliers. This approach is based on assigning a cooperative outlier factor to each object and recognizing the set of candidate outliers after each merging step in the cooperative clustering model. The CCOD algorithm relies on the fact that cooperative clustering outperforms non-cooperative clustering to achieve better detection of outliers in the data. Experimentally, the CCOD is applied on both healthcare gene expression datasets and news text document datasets. Undertaken experimental results indicate that CCOD works better than the adopted traditional clustering-based outlier detection techniques with better improvement in the clustering quality after removing the identified set of outliers.

4 - Managing the world's largest dance festival in India: An operational framework
Narasimhan Ravichandran

As a part of religious belief and promote socialization, a dance festival is organised in various parts of Western India in the month of September. One such notable event happens in the state of Gujarat, where 15,000 young men and women dance for six hours everyday for nine days. This talk documents the managerial challenges involved in this and discusses the innovative approaches adopted by the organisation to conduct the festival incident free. Significant lessons can be drawn to mange a large event from this experience.

■ HD-29

Thursday, 15:00-16:30 - 303B

Models for energy and environmental issues

Stream: Long term planning in energy, environment and climate
Invited session
Chair: *Olivier Bahn*
Chair: *Salvador Sandoval*

1 - Cross-border pollution and environmental quota
Salvador Sandoval, Pedro Luis Celso Arellano

This work develops a Cournot's oligopoly model, of partial equilibrium, under reciprocal dumping restraints between two countries. The domestic companies allocate part of their production to the local consumption and the rest to the export market. Firms generate pollution in their productive processes, but they possess technology to reduce externalities. We use an instrument of environment policy: quota. We suppose that exist croos-border pollution, i.e, the countries involved in the reciprocal dumping export part of their pollutants to another country, and the remaining emissions are assimilated in the producing country. The pollution quantities the companies yield in each country are distributed in direct proportion to the quantities produced of the good for local consumption and the export market. The results are: a) if the marginal cost for polluting is very high, then government sets up the minimal quota, i.e, it doesn't allow emissions from the companies, putting more value on the harmful effects of such emission to the environment over the other components of the well-being function; b) the most inefficient country imposes the major quota of pollution, which implies that government favors the competitiveness of the local companies, allowing them a higher level of pollutants for reducing costs and increasing productivity.

2 - Exploring deep decarbonization pathways to 2050 for Canada using an optimization energy model framework
Olivier Bahn, Kathleen Vaillancourt, Erik Frenette, Oskar Sigvaldason

The main objective of this paper is to explore deep decarbonization pathways for the Canadian energy sector that would allow Canada to participate in global mitigation efforts to keep global mean surface temperatures from increasing by more than 2' Celsius by 2100. Our approach consists in deriving minimum cost solutions for achieving progressive emission reductions up to 2050 using the North American TIMES Energy Model (NATEM), a detailed multi-regional and integrated optimization energy model. With this model, we analyze a baseline and two 60% reduction scenarios of combustion related emissions by 2050 from 1990 levels, with different assumptions regarding projected demands for energy services and availability of technology options for carbon mitigation. The first reduction scenario includes only well-known technologies while the second one considers additional disruptive technologies, which are known but are not fully developed commercially. Results show that three fundamental transformations need to occur simultaneously in order to achieve ambitious GHG emission reduction targets: electrification of end-use sectors, decarbonization of electricity generating supply, and efficiency improvements. In particular, our results show that electricity represents between 52% and 57% of final energy consumption by 2050, electricity generating supply achieves nearly complete decarbonization by 2025 and final energy consumption decreases by 20% relative to the baseline by 2050.

3 - Assessing butanol from integrated forest biorefinery: A combined techno-economic and life cycle approach
Annie Levasseur, Olivier Bahn, Didier Beloin-Saint-Pierre, Mariya Marinova, Kathleen Vaillancourt

The life cycle assessment (LCA) methodology is increasingly used to ensure environmental sustainability of emerging biofuels. However, LCA studies are usually not performed at the process design stage, when it would be more efficient to identify and control environmental aspects. Moreover, the long-term economic profitability of biofuels depends on future energy and climate policies, which are usually not considered in techno-economic feasibility studies. This paper proposes a holistic approach, combining the LCA method and a TIMES energy system model, to offer a simultaneous assessment of potential environmental impacts and market penetration under different energy and climate policy scenarios of emerging energy pathways. The approach is applied to butanol produced from pre-hydrolysate in a Canadian Kraft dissolving pulp mill. Results show that 1) the energy efficiency of the butanol production process is a critical aspect to consider in future design and implementation steps in order to make butanol a competitive fuel among all other alternative fuels, 2) with a 50% internal heat recovery, butanol has a role to play in the transportation sector under climate policy scenarios, and 3) higher supply costs for feedstock might undermine the competitiveness of butanol on the medium term (2030), but probably not on the long-term (2050).

4 - Long-term energy modeling for a decarbonized world: An assessment of the Paris agreement with an optimization bottom-up model
Sandrine Selosse, Seungwoo Kang, Nadia Maïzi

A historic international climate agreement was adopted by all 195 parties at the UNFCCC on December 2015, to respond to climate issue. The 21st Conference of Parties (COP 21) then marked a decisive stage in the transition to a decarbonized world, with countries calling for a more ambitious long-term goal. Using a long-term prospective approach, and more precisely the bottom-up optimization model TIAM-FR, we investigate different decarbonization pathways of the world energy system to reach the 2'C UNFCCC objective on the one hand, and assess the Paris Agreement with the Nationally Determined Contributions (NDCs) on the other hand. Our analysis then focuses on the effects of the Paris Agreement on the level of GHG emissions and the corresponding technological solutions in global and regional perspectives (developed, fast developing or developing countries). While the global contribution of all countries appears essential to reach the ultimate goal of the Paris Accord, a fair level of contribution from developing countries has to be determined; we then discuss the principle of common but differentiated responsibilities. Climate constraints tending toward a 2'C objective involving significant decarbonization of the power system with considerable investments in renewable energies as well as in carbon capture and storage technologies, notably with bioenergy, we discuss the role of this option and of the biomass potential.

■ HD-30

Thursday, 15:00-16:30 - 304A

Advances in health care management

Stream: Health care management
Invited session
Chair: Inês Marques
Chair: Erik Demeulemeester

1 - Optimal branch-and-check approaches to bi-linear mixed-integer nonlinear programming with an application to caseload balanced distributed operating room scheduling
Vahid Roshanaei, Curtiss Luong, Dionne Aleman, David Urbach

We develop two novel optimal branch-and-check (B&C) approaches to mixed-integer nonlinear programming (MINLP) models for location-allocation with caseload balancing. The nonlinearity in the MINLP model is due to the product of binary variables (bi-linearity). We motivate our B&C methods with an application to the balanced distributed OR scheduling (BDORS) problem in the University Health Network (UHN), consisting of three collaborating hospitals: Toronto General Hospital, Toronto Western Hospital, and Princess Margaret Cancer Centre in Toronto, Ontario, Canada. The two approaches, a uni- and a bi-level B&C, are based on a reformulation-decomposition technique. The uni-level B&C method decomposes the model into a surgical suite location, operating room (OR) allocation, and macro balancing master problem and micro OR balancing sub-problems for each hospital-day. The bi-level approach uses a relaxed master problem, consisting of a location and relaxed allocation/macro balancing master problem and two optimization sub-problems. The primary SP is formulated as a bin-packing problem to allocate patients to open operating rooms to minimize the number of ORs, while the secondary SP is the uni-level micro balancing SP. Using UHN datasets, we show that both B&C approaches converge to 2% optimality gap, on average, within 30 minutes runtime. Additionally, we show that convergence of each B&C varies depending on where in the decomposition the actual computational complexity lies.

2 - What you should know about models in operating room scheduling
Carla Van Riet, Erik Demeulemeester, Michael Samudra

In hospitals, the operating room (OR) is a particularly expensive facility and thus efficient scheduling is imperative. This can be greatly supported by using advanced methods that are discussed in the academic literature. In order to help researchers and practitioners to select new relevant articles, we classify the recent OR planning and scheduling literature regarding patient type, used performance measures, decisions made, OR up- and downstream facilities, uncertainty, research methodology and testing phase. Based on these classifications, we identify trends and promising topics. Additionally, we recognize three common pitfalls that hamper the adoption of research results by stakeholders: the lack of a clear choice of authors on whether to target researchers (contributing advanced methods) or practitioners (providing managerial insights), the use of ill-fitted performance measures in models and the failure to understandably report on the hospital setting and method related assumptions. Inspired by work on a real-life hospital setting, we developed specific guidelines that help to avoid these pitfalls when building models for OR scheduling problems.

3 - Using buffer capacity in the operating room planning: A good idea?
Erik Demeulemeester, Carla Van Riet

In surgery scheduling it is almost daily practice that the schedule cannot be executed as planned, leading to undesired rescheduling of patients or even to the cancellations of surgeries. One way to cope with this is to install buffers in the surgery schedule. These buffers can then be used to absorb the variability resulting from for instance errors in the estimation of the surgery duration, the arrival of non-elective (urgent and emergent) patients, variable turnover times and surgeons or nurses arriving late. Unfortunately, installing buffers results in less capacity being available for planning purposes and as a result will affect the number of served elective patients. Therefore, the question raises whether and in which cases it is reasonable to install buffer capacity and which type of buffer capacity results in relatively better performances. This talk discusses our findings on this topic. We used a detailed simulation model that was built in close collaboration with a large university hospital in Belgium in order to ensure practically implementable insights.

4 - Staff scheduling at an emergency medical service
Inês Marques, Joana N Rosa, Hendrik Vermuyten, Ana Barbosa-Povoa

The aim of this work is to develop an automated tool embedded by optimization methods to help the current manual procedures for staff scheduling at the Portuguese National Institute of Medical Emergency (INEM). INEM has a wide range of assistance resources (different types of ambulances, motorcycles, and helicopters). The crew assigned to each assistance resource needs to have specific skills, and can be composed by emergency medical technicians, nurses and doctors. In addition, staff also works at the dispatch centers existent at INEM. Thus staff is not completely disjoint and thus should not be scheduled separately. Following the problem characteristics, this work proposes an approach to elaborate integrated staff working schedules for the existent assistance resources and for the dispatch centers. Working schedules are constructed according to current legislation and working internal regulations at INEM, while seeking to maximize personnel satisfaction. The schedules provided by the proposed optimized approach are compared with the current handmade schedules.

■ HD-31

Thursday, 15:00-16:30 - 304B

Managing student projects

Stream: Initiatives for OR education
Panel session
Chair: Peter Bell

1 - Student projects: Opportunites and challenges
Peter Bell

The student project is a common feature of the analytics course. Student projects provide both opportunities and challenges. This session will present the experiences of several faculty who have managed a variety of student projects with a view to exploring how to maximize the benefit of the project for the student and/or client while controlling the challenges.

2 - Managing student projects: Over 40 years of experience
Graham Rand

A significant component of how the Department of Management Science at Lancaster University prepares Masters students for careers as OR practitioners is a 4-month consultancy project for an external client. Following a brief historical introduction, the nature of the OR projects is described, together with summaries of recent typical projects. The arrangements for setting up and managing projects follows, including the difficulties that have arisen from changing client organisational cultures, the increasingly multinational make-up of the student cohort and the competition for projects from similar courses. Supporting activities used to prepare students for projects are described, followed by discussion of the tricky problem of allocating students to the available projects. Finally the requirements for supervising students during the project are discussed, including the dissertation requirements, which include a strong element of reflection so as to enhance the project-learning experience.

3 - Learning lessons in managing student projects
Mehmet Begen

In this talk we share our experiences in managing undergraduate and graduate student projects on analytics. We discuss the ingredients needed for a successful implementation of projects in a course or projects for industry (e.g., company projects, internships). We also present challenges in managing these projects and discuss what works best.

Thursday, 16:45-18:15

■ HE-01

Thursday, 16:45-18:15 - 307B

Advances in network design

Stream: Telecommunications and network optimization
Invited session
Chair: *Eric Gourdin*
Chair: *Brigitte Jaumard*

1 - Optimizing optical fiber networks
Matthieu Chardy, Vincent Angilella, Walid Ben-Ameur

The transformation of telecommunication services leads to natural growth of customers need for bandwidth, forcing telecommunication operators to upgrade the capacity of their network. This necessary increase in network capacity affects many types of networks and notably wireline networks, one major transformation being known as Fiber To The Home rollout, i.e. the replacement of the copper wires of the legacy fixed access network by optical ones. The presentation focuses on optimization problems related to optical fiber network design and deployment (called FTTx networks), embedding cabling-related specific issues. Integer Linear models are proposed and assessed on real-life instances from French areas with moderate density of population.

2 - Layered graph approaches for the directed network design problem with relays
Martin Riedler, Markus Leitner, Ivana Ljubic, Mario Ruthmair

We consider mixed integer linear programming models for the directed network design problem with relays (DNDPR) based on layered graphs. DNDPR originates from telecommunication network design but also has applications in hub location and electric mobility. The problem is based on a family of origin-destination pairs and a set of arcs that can be established in the network. A subset of arcs has to be selected in order to allow communication between all these pairs but communication paths must not exceed a certain distance limit. To transmit the signal farther, regeneration devices (relays) have to be installed. The goal is to allow all pairs to communicate while minimizing the costs for establishing arcs and relays. Previous work in the area involves a node-arc formulation and a branch-and-price approach. We propose two compact formulations and a model based on an exponential number of constraints. The latter is solved using a branch-and-cut algorithm. An experimental study demonstrates the effectiveness of our novel formulations on a diverse set of benchmark instances.

3 - Robust and reliable virtualised network infrastructures
Varun S Reddy, Andreas Baumgartner, Thomas Bauschert

Concepts like Software-defined Networking (SDN) and Network Functions Virtualisation (NFV) are expected to be key enablers for a new dimension of flexibility in the deployment, operation and maintenance of future communication networks. They also allow realisation of multiple virtual networks (multi-tenancy) on a common substrate network infrastructure. Provisioning such virtual networks requires efficient resource allocation mechanisms so that the utilisation of the substrate infrastructure provider can be maximised. In this context, the design of individual virtual network slices and their mapping onto the underlying substrate network is of major importance. We refer this problem as the Network Slice Design Problem. In this work, we first propose an optimisation model (ILP) for the general network slice design problem. In the next step, we extend the problem formulation to cope with uncertainties in the user traffic demands by using the well known concept of Gamma-robustness. We next present a simple model extension which protects the robust virtual network slices from single substrate element outages using the concept of 1+1 protection (robust SNSDP). Finally, we derive an alternate model that uses shared capacity resources to offer both survivability and robustness guarantees. A performance evaluation is presented comparing the new approach with the robust and robust + survivable counterparts of the network slice design models using example network topologies from SNDlib.

4 - Minimum network migration cost and duration
Brigitte Jaumard, Hamed Pouya, Catherine Preston-Thomas

SDH and SONET networks are still widely used in metro network data infrastructure. However, over the next decade, they will be replaced by new infrastructures, e.g., IP- centric and SDN-enabled networks, throughout network migra- tion that can take several months to a couple of years, in order to minimize the number of network disruptions. Consequently, telecommunication companies are looking for optimization algo- rithms to efficiently manage their network migration resources (technicians and engineers) and duration. In this talk, network migration problem is considered as a set of circuit migration problems in which two technicians simultaneously migrate the two ends of a circuit in order to minimize the customer Grade of Service (GoS). We study the problem of finding a technician schedule so as to minimize the overall network migration cost while satisfying technical and operational constraints. We provide an original and efficient technician scheduling algorithm that we validate and test on several Ciena's customer network migration data sets.

■ HE-02

Thursday, 16:45-18:15 - 308B

Applications of queueing theory

Stream: CORS SIG on queueing theory
Invited session
Chair: Steve Drekic

1 - Exact analysis of the (R,Q) inventory policy in a two-echelon production-inventory system
Ata G.Zare, Hossein Abouee-Mehrizi, Oded Berman

We consider a two-echelon production-inventory system with a single manufacturer and a distribution center (DC). The manufacturer has a finite production capacity, and the transportation times between the two echelons are generally distributed. We assume that customers arrive at the DC according to a Poisson process and consider the continuous review (R,Q) inventory policy at the DC. We assume that the manufacturer operates from a warehouse using a base-stock policy to manage its inventory and derive the waiting time of an order in the manufacturer used to find the average total cost of the system. Using these results, we derive the optimal reorder point at the DC. We propose a heuristic method to find the 'optimal' solution for the base-stock level in the warehouse, and the reorder point and batch order size at the DC.

2 - A better model for job redundancy: Decoupling server slowdown and job size
Kristen Gardner, Mor Harchol-Balter, Alan Scheller-Wolf

Recent computer systems research has proposed using redundant requests—creating multiple copies of the same job and waiting for the first copy to complete service—to reduce latency. In the past few years, queueing theorists have begun to study redundancy, first via approximations, and, more recently, via exact analysis. Unfortunately, for analytical tractability, most existing theoretical analysis has assumed a model in which the replicas of a job each experience independent runtimes (service times) at different servers. This model is unrealistic and has led to theoretical results which can be at odds with computer systems implementation results. We introduce a much more realistic model of redundancy. Our model allows us to decouple the inherent job size (X) from the server-side slowdown (S), where we track both S and X for each job. Analysis within the S&X model is, of course, much more difficult. Nevertheless, we design a policy, Redundant-to-Idle-Queue (RIQ) which is both analytically tractable within the S&X model and has provably excellent performance.

3 - Asymptotic performance of energy-aware multiserver queueing systems with setup times
Vincent Maccio, Douglas Down

An intuitive solution to address the immense energy demands of data centres is to turn servers off to incur fewer costs. However, when to turn a specific server off, and when to then turn that server back on, are far from trivial questions. As such, many different authors have modeled this problem as an M/M/c queue where each server can be turned on, with an exponentially distributed setup time, or turned off instantaneously. Due to the complexity of the model analysis, authors often examine a specific policy. Moreover, different authors examine different policies under different cost functions. This in turn causes difficulties when making statements or drawing conclusions regarding competing policies. Therefore, we analyze this well established model under the asymptotic regime where the number of servers approaches infinity, while the load remains fixed, and show that not only are many of the policies in the literature equivalent under this regime, but are also optimal under any cost function which is non-decreasing in the expected energy cost and response time.

4 - Performance approximation of emergency service systems with multiple priorities and partial backups: An extension of the approximate hypercube queueing model
Akbar Karimi, Michel Gendreau, Vedat Verter

An extension of the approximate Hypercube Queueing Model is presented where we relax the full-backup assumption in the sense that each demand node may be serviceable by an arbitrary subset of servers (partial backup). Moreover, we allow requests for service to be of different priorities and let service times depend on the call type and the demand and server locations. We consider systems with zero and infinite queue capacities and to approximate the distribution of the number of busy servers, we introduce a family of queueing systems with partial admissions and obtain its steady-state distribution using elementary arguments based on extensions to Little's Law that were obtained earlier. The validity of the model and its efficiency and accuracy in approximating the performance of a typical Emergency Service System are studied through a realistic application of locating a fleet of ambulances in downtown Montreal, Canada.

■ HE-04

Thursday, 16:45-18:15 - 202

Job and flow shop scheduling

Stream: Scheduling in job shops, flow shops, and healthcare
Invited session
Chair: Julia Lange

1 - GPU parallel computing for job shop scheduling in manufacturing
Radoslaw Rudek, Izabela Heppner

We analyse a real-life manufacturing problem in a medical area, where the objective is to assign jobs to workers and determine their schedule to optimize given time-cost criteria under defined production constraints. To face the problem, we propose a job shop scheduling model enhanced by factors relevant to the practical aspects of the analysed case study, which refer to competence, productivity, availability, maintenance activities / rest of workers (machines) and release dates, due dates, deadlines, potential preemption, precedence constraints of jobs. Moreover, we design an efficient representation of a schedule and related data structures to efficiently calculate job completion times such the time complexity depends only on the number of jobs and machines (workers), but not on the scheduling period. Thereby, we are able to efficiently calculate various related time-cost criteria. On this basis, we construct heuristic and metaheuristic algorithms to solve the considered problem under different criteria. However, the most attention is focused on the developed parallel tabu search algorithm on Graphics Processing Units (GPU) using Compute Unified Device Architecture (CUDA), which is several hundred times faster than a typical implementation.

2 - On job shop scheduling with convex costs and its application to just-in-time scheduling
Reinhard Bürgy, Kerem Bulbul

We address an extension of the classical job shop scheduling problem with a generic convex cost objective. This objective makes it possible to model, for example, convex storage, earliness and tardiness costs as well as storage time restrictions and controllable processing times. Based on a disjunctive graph formulation of the problem, we develop a tabu search heuristic in which neighbors are built by swapping a critical arc. For this purpose, we use and extend the standard concept of critical arcs to the problem under study. Actually, for a feasible selection, which specifies the sequence of operations on each machine, we solve the resulting timing problem with a convex cost network flow algorithm proposed by Ahuja, Hochbaum and Orlin (Management Science, 2003). This algorithm provides a primal solution, an optimal flow, as well as a dual solution, an optimal potential. The potential gives, in fact, the timing solution while the flow provides a neat way to define the criticality of arcs. We apply the solution method to just-in-time scheduling problems with linear storage and earliness costs and superlinear tardiness costs. The computational results support the validity of our approach. It is, to the best of our knowledge, the first comprehensive experimental study of a just-in-time job shop scheduling problem with nonlinear costs.

3 - A homogenous parallel lines scheduling problem
Arshad Ali, Tarek ElMekkawy, Yuvraj Gajpal

Hybrid flow shop (HFS) is a common machine set up for different manufacturing industries. In HFS, jobs are processed through multiple available machines to achieve higher utilization of resources. This paper considers the special case of hybrid flow shop problem where machines are arranged in parallel lines. Each line has multiple stages but the number of stages in each line are same. Each line is considered to be complete on their own hence a job is required to go through only one of the lines to become final product. One job can be assigned to only line. The problem involves finding job sequence for each line to minimize the total completion time of jobs. Three heuristics and a metaheuristic has been developed to solve the problem. A benchmark problem instances has been used to evaluate the performance of the proposed heuristics and metaheuristic.

4 - A simulated annealing approach to solve job-shop scheduling problems with blocking constraints
Julia Lange, Frank Werner

The classical job-shop scheduling problem is one of the well-studied models in scheduling research. Including a real-world aspect, the consideration of blocking constraints refers to the absence of buffers in a production system. In case that the succeeding machine is not idle, a job will block the machine until its processing can be continued. The resulting blocking job-shop problem is complex due to additional interdependencies of different jobs on different machines. Mathematical programming results give evidence to the necessity of efficient heuristic methods to obtain near-optimal solutions even for small instances. There are two major challenges in the application of a heuristic approach to this problem. First, a permutation of operations, which does always define a feasible schedule for the classical job-shop problem, is not necessarily giving a feasible schedule with regard to blocking constraints. Second, it is not clear how to complete and repair a partial solution to determine feasible neighbors of a solution. For the blocking job-shop problem a procedure is presented, which generates a feasible schedule from any given permutation of operations. Additionally, a neighborhood is derived applying adjacent pairwise interchanges together with a technique to repair and complete partial solutions and construct feasible neighbors. Both mechanisms are implemented in a simulated annealing metaheuristic and tested with regard to the minimization of total tardiness.

■ HE-05
Thursday, 16:45-18:15 - 203

Dynamic programming 2

Stream: Dynamic programming
Invited session
Chair: Lishun Zeng

1 - Primal adjacency-based algorithm for solving the shortest path problem with resource constraints
Ilyas Himmich

We propose in this work a new exact primal method for solving the shortest path problem with resource constraints. Our algorithm performs a search in the neighbourhood of a set of source-task paths. We first define the notion of adjacency in the context of the SPPRC. Then, we extract some polyhedral properties that are useful in the definition of the neighbourhood as it is explored by our algorithm. Computational results show the effectiveness of our solution approach in comparison with the classical Dynamic Programming algorithm.

2 - A stochastic decision making model of emergency response to mass casualty incidents in multi-disaster areas
Yunzhu Lin

Response to mass casualty incidents caused by accidents is one of the greatest challenges to medical emergency response systems. During the emergency response to mass casualty incidents decisions relating to the extrication, transporting and treatment of casualties are made in a sequential manner. In this paper, the stochastic nature of casualty health and treatment time are considered to determine ambulance dispatches assignment. We assume the uncertainty follows "Markov chain" properties in which the correlations of the variations in the consecutive periods are high and the severity status of casualties in next period is stochastically determined by the present one. A novel stochastic dynamic programming model is proposed and can help avoid myopic decision making of the response operation which could result from the use of a sequential, heuristic decision making process. The total response times of casualties at the different levels of injury severity, including waiting times at emergency sites and hospitals, transportation times, and treatment times, are minimized. We utilize a lexicographic view to combine these objectives in a manner which capitalizes on their ordering of priority. That is, injuries of higher level of severity have higher priority. Furthermore, a simulation-based approximate dynamic programming algorithm is developed to solve the proposed model. The model is evaluated over several potential problems, with results confirming its effective nature.

3 - Accelerating strategies in label setting algorithms for the resource constrained shortest path problems
Lishun Zeng, Mingyu Zhao

In this work, we present the design and implementation of an efficient yet flexible solution framework for the resource constrained shortest path problems (RCSPP). Several accelerating strategies have been devised in the framework to improve the performance of generic label setting algorithms based on dynamic programming. We apply the skyline algorithms developed in the database community to speed up the computation of pareto optimal labels. We design a dynamic memory allocator for labels based on binary heaps to improve data locality and computational efficiency of label dominance. Several parallelization strategies of the algorithms are implemented and discussed as well. Moreover, we present an application of the framework on the airline crew pairing problem, where most state-of-the-art approaches for RCSPP in the literature, e.g. network reduction strategies or the pulse algorithm, are not applicable. Numerical experiments on internal benchmark problems show that our implementation is in general an order of magnitude faster than that of the Boost Graph Library.

■ HE-06

Thursday, 16:45-18:15 - 204A

Case studies in problem structuring methods

Stream: Problem structuring interventions
Invited session
Chair: Robert Dyson

1 - Evaluating the use of problem structuring methods to guide anticipatory intervention within the United Kingdom ministry of defence

David Lowe, Karen Clark, Gerald Midgley, Mike Yearworth

The Defence Science and Technology Laboratory (Dstl) has recently developed and implemented a number of Problem Structuring Method (PSM) approaches to assess organisational health within the United Kingdom Ministry of Defence. In particular Dstl has used these PSMs to support anticipatory intervention in the areas of acquisition, infrastructure and headquarter functions. We revisit each of these three cases to evaluate whether the use of PSMs has led to benefits in the long term, and in particular to understand what it was about each PSM application that helped to deliver these benefits. The presentation will introduce the evaluation method, detail the findings for each of the case studies, and discuss the methodological lessons that have been identified.

2 - Waste remediation at an industrial legacy site: Combining PSMs with boundary critique

Amanda Gregory, Jonathan Atkins, Gerald Midgley

Problem Structuring Methods (PSMs) were created for use in situations characterised by the existence of multiple actors with claims to a stake in the issue of concern. Hence it is well accepted that there is a need to account for who is involved in any PSM based intervention. However, this need is commonly met through uncritical accounts of stakeholder salience, the quality of being particularly noticeable or important, rather than through rigorous investigation of who ought to be involved based on moral and/or ethical considerations. Such a critical approach is well established in the systems literature and referred to as boundary critique. In this paper we demonstrate the practical relevance of combining boundary critique and PSMs through the case of a stakeholder workshop concerned with waste remediation at a steel production legacy site in the North of England. Our case demonstrates that issues evolve over time with the chronology of events and their framing having subsequent effects on which actors are regarded as having a legitimate stake in the issue of concern, the articulation of values and the evaluation of different future options. In discussing our case, we highlight the need to embrace being critical about boundaries in multiple senses, not just in terms of who is involved but also temporal and other boundaries.

3 - Combinatorial scenario spaces: A framework for morphological analysis and similar methods

Christian Carling

Morphological Analysis (MA) is a versatile method for scenario analysis, well-proven in practical use. The basic concept, combinatorial generation of complex scenarios from simple components, followed by restriction of incompatible sub-scenarios, is simple and has been frequently and independently re-discovered. As a result, there exists a number of similar variants, e.g. Field Anomaly Relaxation, the Batelle approach and Cross Impact Analysis. Examples can also be found outside scenario analysis, e.g. in software testing. Combinatorial Scenario Spaces (CSS) is a framework that generalises the internal structure and functions of these methods. It is defined using elementary concepts from set theory and order theory, mirroring the basic structure of Dempster-Shafer and Possibility theory. The purpose is twofold: to provide tools for improving current implementations, and to present a common framework for methodological discussions and development. A key challenge in applying MA to real-world problems is the vast size of the resulting scenario spaces. Most applications resort to different ways of clustering or sampling the scenario space. Partition matroids are introduced as a natural way to represent the complex scenario space, by grouping together scenarios that are maximally similar in composition. This is shown to be useful in algorithm design, e.g. for clustering and finding optimal subsets.

4 - Health and safety factors that impact worker's productivity in the construction industry in Brazil

Fabio Henrique Cordeiro, Mischel Carmen N. Belderrain, Alberto Paucar-Caceres

Social Service of Industry (SESI) is a network of non-governmental organizations in Brazil. Its objective is to provide high-quality professional education, focused on increasing productivity in industry, as well as to promote the well-being of workers. This paper aims to identify the health and safety factors that impact worker's productivity in the construction industry by using the Strategic Options Development and Analysis (SODA) method. The problem structuring was accomplished from a document-based analysis which led to the development of three cognitive maps. Four stakeholders from the construction industry were consulted to validate the final aggregate map. The following factors of occupational health and safety (OSH) were obtained: Invest in models of consulting in OSH management; Foster the networks of the construction sector to improve the communication of OSH solutions / programs; Invest in the professional educational background of the work. Implement the Conditions and Environment Program for Work in the Construction Industry from the planning of the project, execution and monitoring of indicators. Finally, the results of this analysis allow the development of strategic options for SESI regarding the definition of suitable solutions for the construction sector, with a possible extension to other sectors of the industry, as well as supporting future decisions.

■ HE-07

Thursday, 16:45-18:15 - 204B

Routing with time windows

Stream: Vehicle routing
Invited session
Chair: Diego Cattaruzza

1 - Pickup and delivery problem with time windows and transfers

Afonso Sampaio, Lucas Veelenturf, Tom Van Woensel

We consider the Pickup and Delivery Problem with Time Windows and Transfers (PDPTW-T). In this problem, a set of transportation requests needs to be satisfied by a vehicle fleet and each request is associated with an origin, destination and specific time windows for service. Transfer points are locations in the network where requests can be transferred between vehicles and temporarily stored. Those transfer opportunities might help to facilitate constructing and maintaining more cost-effective and robust transportation plans. In this preliminary work, we investigate static settings, i.e., all requests (location and time windows) are known before the optimization, and identify circumstances in which transferring requests lead to improvements as well as suitable solution methodologies to tackle the problem. Based on these results, our goal is to investigate how transfers could provide the means for better routing strategies under a dynamic setting, in which the set of transportation requests arrive in real-time and the routing plan needs to cope with the new information.

2 - Analyzing the traveling salesman problem with time windows using dependency graphs

Christian Truden, Philipp Hungerländer

The strongly NP-hard Traveling Salesman Problem with Time Windows (TSPTW) is concerned with visiting a set of customers within their assigned time windows such that a given objective function is minimized. We introduce dependency graphs as a concept for analyzing and illustrating the structure of TSPTW instances. The vertices of a dependency graph correspond to the time windows of an associated TSPTW instance. A directed edge between an ordered pair of time windows is contained in the graph if and only if there is a customer from the second time window who can potentially be visited directly after a customer who is serviced during the first time window. Hence dependency graphs illustrate which edges between pairs of customers from different time windows must be included in the TSPTW model and which edges can be omitted without removing feasible solutions. Also note that cycles in the dependency graph correspond to possible subtours that can occur between customers assigned to different time windows. In our talk we further demonstrate the benefits of dependency graphs as a preprocessing technique in a computational study and present applications, where sparse dependency graphs appear and hence the corresponding TSPTW models can be solved quite efficiently.

3 - A branch&cut algorithm for the multi-trip vehicle routing problem with time windows
Diego Cattaruzza, Paolo Gianessi

The Vehicle Routing Problem with Time Windows (VRPTW) aims at determining the trips of a fleet of capacitated vehicles to deliver a set of customers, while complying time windows associated with them, in order to minimize the travelled distance. The additional feature of the Multi-Trip VRPTW (MTVRPTW), which recently got the attention of scholars mostly due to its application to city logistics, is to allow vehicles to perform a sequence of trips, called a journey, under a maximum shift length. Moreover, in its most frequent form, which we address, the MTVRPTW presents service-dependent loading times, i.e. the time to recharge depends on the total service time of the subsequent trip. Other variants exist that consider e.g. profits or trips with limited duration. We propose a two-index MILP formulation for the MTVRPTW that makes use of base and replenishment arcs, which allow to represent a journey as an elementary path with both endpoints in the depot. Time windows, shift length, and service-dependent loading time constraints are imposed via specific sets of variables. The use of classical capacity constraints to enforce the load limit on vehicles leads to a B&C algorithm. In order to tighten the lower bound obtained from the linear relaxation of the proposed MILP model, we consider path valid inequalities. Tests have been conducted on a set of instances with up to 50 customers and 4 vehicles, with promising results.

■ HE-08
Thursday, 16:45-18:15 - 205A

Advances in modelling incomplete preference information

Stream: Decision analysis
Invited session
Chair: Juuso Liesiö

1 - Spatial multiattribute decision analysis with incomplete preference information
Mikko Harju, Juuso Liesiö, Kai Virtanen

Decision alternatives in spatial decision analysis have consequences that vary across a geographical region. We present necessary and sufficient conditions for representing preferences among such decision alternatives with an additive spatial value function. The value function is challenging to construct as it requires assigning an infinite number of spatial weights representing the relative importance of subregions. To overcome this challenge, we introduce a method for capturing incomplete preference information on spatial weights and identifying the resulting dominance relations among decision alternatives. This allows for the computation of the non-dominated decision alternatives. The method can also be applied with multiattribute consequences and incomplete preference information on attribute weights. We demonstrate the use of the method with an application in military planning. It deals with the selection of positions for air bases in order to maximize the resulting air defense capability.

2 - The efficient frontier implied by the second-order stochastic dominance
Juuso Liesiö, Markku Kallio

Second-order Stochastic Dominance (SSD) provides decision recommendations among uncertain alternatives without requiring the exact specification of the decision maker's (DM's) risk preferences. In particular, if an alternative is dominated in the sense of SSD, it is not the preferred choice of any risk-averse DM with a concave utility function. However, it is difficult to use SSD in problems in which the decision alternatives correspond to the feasible solutions of an optimization problem (e.g., resource allocation decisions, project portfolio selection). This is since there does not exist any approaches for generating the set of those feasible solutions to a stochastic optimization problem which are not stochastically dominated by some other feasible solution. We address this shortcoming in the current literature by developing a method to identify the entire set of SSD non-dominated solutions to a stochastic optimization problem. The method is illustrated by applying it to financial portfolio optimization.

3 - A new correlation coefficient for aggregating incomplete rankings equitably
Adolfo R. Escobedo

The consensus ranking problem is central to group decision-making. It involves finding an ordinal evaluation which minimizes the collective disagreement relative to a set of individual preferences over a set of competing objects; two common examples are corporate project selection and academic paper competitions. Although different measures for quantifying agreement between rankings can be employed, those founded on axiomatic distances are regarded as the most suitable due to their intuitive appeal and social choice-related axiomatic properties. This work introduces a ranking correlation coefficient founded on the Kendall tau distance metric, and it establishes its equivalence to an axiomatic ranking distance designed to handle a realistic variety of ranking formats including those containing non-strict (i.e., with-ties) and incomplete (i.e., null) preferences. Moreover, it demonstrates that alternative ranking correlation coefficients inadvertently introduce systemic biases when considering the same variety of preferences, thus rendering them inadequate for aggregating rankings in the general case. The efficacy of the presented ranking correlation coefficient to solve the consensus ranking problem and to provide alternative optimal solutions is illustrated via computational results of a new combinatorial branch-and-bound algorithm.

■ HE-09
Thursday, 16:45-18:15 - 205B

Quantitative approaches in management and economics

Stream: Simulation in management accounting and control
Invited session
Chair: Eleonora Fendekova

1 - Microeconomics models of quantitative analysis the degree of concentration in the Slovak banking sector
Eleonora Fendekova, Michal Fendek

The paper focuses on the presentation of a microeconomic model instruments for the support of competitive environment protection in banking sector in Slovakia. A competitive environment is an attribute of virtually every aspect of economic relations. A characteristic feature of the market environment is dynamism, a constant change which is induced by an effort to reach maximum competitiveness. Functioning of a market mechanism is conditioned by the existence of a good market conditions for which respecting the conditions of economic competition is necessary. The competitive environment is occurred in each field of life. A dynamism and flux are typical features, which is caused by efforts to achieve maximum competitiveness. The functioning of the market mechanism is subjected to the existence of good market conditions, for which to comply with conditions of a competition is necessary. The aim of this paper is to evaluate the competitive environment and analyze the concentration of the banking sector in Slovakia. Under the conditions of the economy of Slovakia the guarantee represents the Antimonopoly Office, which systematically takes into account the analysis of the competition state in the banking sector. The purpose of this paper is to present some results of quantitative analysis of the state and development of the Slovak banking sector during 2010 - 2016. This paper is based on the co-operation of the authors with the Antimonopoly Office of the Slovakia.

2 - Objective functions in empirical asset pricing: An economic analysis
Thomas Otto

Empirical asset pricing uses regression analyses to explain stock returns by means of three (Fama/French (1993)), four (Carhart (1997)), or five (Fama/French (2015)) factors. However, why should investors care about minimizing the sum of squared residuals? For potential buyers an overestimation of prices seems to be more severe than an underestimation. This problem of asymmetry is addressed by the literature (e.g., Allen/Singh/Powell (2009)) with the help of quantile regressions. From an economic perspective the question arises why investors should choose at all a statistical approach where the following idea appears to be more natural. If an investor was interested in an asset with certain properties (earnings, beta factors etc.), he would choose a subset of the assets used in the regressions that offers at least these properties, but possesses the lowest price. Given this observation, we aim at analyzing the implicit economic assumptions behind several regression approaches and judge them based on our findings. Applying a methodology developed by Wilhelm/Brüning (1992) for term structure estimation, we show: first, regressions and quantile regressions imply restrictions on the purchase and short sale of assets that cannot be observed on real financial markets, in which the assumptions implied by quantile regressions are slightly more realistic; second, we express the (verbal) idea of finding the cheapest portfolio of assets into a formal empirical asset pricing model.

■ HE-10

Thursday, 16:45-18:15 - 205C

Location

Stream: Location
Invited session
Chair: Yolanda Hinojosa

1 - Interactive evolutionary multiobjective optimization for facility location problems
Maria Barbati, Salvatore Corrente, Salvatore Greco

We consider facility location problems formulated in terms of multiple objective optimization. In general, what is searched for in this case is the Pareto set of efficient solutions. This is a problem much more difficult than the already quite complex problems of optimizing a single objective function. Moreover, obtaining the Pareto set does not mean that the decision problem is solved. Thus, we propose an interactive approach to facility location problems in order to use preference elicited by the decision maker to focus the search on the most preferred part of the Pareto set rather than on its whole totality. We handle this decision problem using an interactive evolutionary multiobjective optimization procedure called NEMOII-Ch. Our approach is very flexible and can be used for solving several multiple objective facility location problems. We apply it to randomly generated instances and in a real world very complex multiobjective location problem with many users and many facilities to be located.

2 - A Lagrange relaxation based approach to solve an undesirable bi-level location model
Zaida Estefanía Alarcón-Bernal, Ricardo Aceves-García

In this work, we propose a solution method for bi-level linear problems with binary variables in the leader problem and continuous in the follower, under the assumption of partial cooperation. The discrete-continuous bilevel problem is reformulated as a single-level one using Karush-Kuhn-Tucker conditions of the follower. This nonlinear model can be linearized by taking advantage of the special structure achieved with the binary variables of the leader problem and solving it through an algorithm based on Lagrangian relaxation. To apply the approach, an undesirable location problem was modeled and solved. Numerical tests are shown.

3 - Locating hyperplanes to fitting set of points
Yolanda Hinojosa, Víctor Blanco, Diego Ponce

This paper presents a family of new methods for locating/fitting hyperplanes with respect to a given set of points. We introduce a general framework for a family of aggregation criteria of different distance-based errors. The most popular methods found in the specialized literature can be cast within this family as particular choices of the errors and the aggregation criteria. Mathematical programming formulations for these methods are stated and some interesting cases are analyzed. It is also proposed a new goodness of fitting index which extends the classical coefficient of determination. A series of illustrative examples and extensive computational experiments implemented in R are provided to show the performances of some of the proposed methods.

■ HE-11

Thursday, 16:45-18:15 - 206A

Production and distribution

Stream: Supply chain management
Invited session
Chair: Maryam Darvish

1 - Simulation-based approach for supply chain optimisation under uncertainty
Songsong Liu, Lazaros Papageorgiou

Managing the supply chains has been becoming increasingly complex. A decision maker is often faced with the challenge to optimise the production and distribution plans for the minimum cost maximum profit under uncertainty. The decision-making under uncertainty become common but difficult problems in nowadays. Such optimisation problems can still be computationally not intractable with large instances or many uncertain parameters. This work addresses a multi-echelon supply chain optimisation problem in the process industry, in which plant capacity expansions, production and distribution plans are to be optimised to achieve the minimum total cost under uncertainty of the product demands in the markets. A mixed integer linear programming model formulation is proposed. To solve the model, a simulation-based solution approach is developed, including a simulation step and a gradient-based optimisation step. The optimisation step determines the key decisions, which are fixed in the simulation step, while the simulation step estimates the total cost and updates the parameters in the optimisation step. These two steps are performed iteratively until the termination criterion is met. The applicability of the proposed model and solution approach is demonstrated by an industry-relevant example.

2 - Solving the grocery backroom sizing problem
Maria Pires, Pedro Amorim

The grocery retail environment is more dynamic today than ever and competition keeps intensifying. This requires retailers to adapt and develop innovative approaches to face the current challenges. However, fresh thinking concerning backrooms is rare, in both academia and practice. In this presentation, we describe a sales forecast model as well as two mathematical programming formulations to solve the grocery backroom sizing problem, which consists in determining the dimension of each storage department in the backroom. The proposed forecasting model is based on clustering techniques and multinomial logistic regressions. Furthermore, two models were developed. The first formulation is a bottom-up approach that aims to reduce the backroom life cycle costs by determining the optimal storage space and height. The second is a top-down approach based on Data Envelopment Analysis that determines the efficient level of storage floor space for each backroom department, based on a comparison with the best practices observed among existing stores. The proposed methodology was tested in more than forty convenience stores, using real data from the largest Portuguese retailer. The application of this methodology in the designing process demonstrates a substantial potential for space savings. The decrease in the storage areas is significant and translates into annual expected increase in profits that range from 330 k EUR for the bottom-up model to 1,2 M EUR for the top-down model.

3 - A heuristic for the integrated order picking-vehicle routing problem in a B2C e-commerce context
Stef Moons, Katrien Ramaekers, An Caris, Kris Braekers, Yasemin Arda

Business-to-consumer (B2C) e-commerce sales are increasing every year. Customers have high expectations regarding online purchases and their delivery. In order to satisfy these customer expectations excellent logistics performance is required. Both the internal warehouse logistic operations and the distribution operations need to be coordinated carefully. Since these operations are interrelated, their interdependence cannot be ignored to avoid suboptimal solutions and inefficient schedules and routes. Thus, instead of solving order picking problems and vehicle routing problems separately using an uncoordinated approach, these two supply chain functions should be integrated into a single optimization problem. The integrated order picking-vehicle routing problem (OP-VRP) considers simultaneously the requirements and constraints of both subproblems. The integrated problem determines picking lists and vehicle routes at a time. E-commerce companies often offer their customers the possibility to select a time frame in which they want to be delivered. Accordingly, time windows are taken into account the integrated OP-VRP. Integration can lead to cost savings and higher service levels. Since the two subproblems are hard to solve to optimality, the integrated problem can only be solved to optimality with an exact solution method for small-size instances. Therefore, a heuristic algorithm using local search operators is developed to obtain solutions in a small computational time.

4 - Sequential versus integrated supply chain optimization
Maryam Darvish, Leandro Coelho

For long, a typical approach towards supply chain planning has been the sequential approach. Ignoring the interlinks between decisions, this approach results in each department of a company making its own decisions, regardless of what other departments are doing, and ignoring the synergy of a global strategy. However, companies are realizing that significant improvements are to occur by exploiting integrated production systems, in which various decisions are simultaneously taken into consideration and jointly optimized. In this talk we compare and assess the performance of sequential versus integrated approaches by studying an integrated location, production, inventory, and distribution problem. Over finite time periods, multiple products are produced in a number of plants, transferred to distribution centers, and finally delivered directly to each customer within a time window. Based on a real case study, we describe, model, and solve this rich integrated problem. The goal is to minimize fixed and variable production costs, inventory, and distribution costs while satisfying demands within a delivery time window. We develop an exact method and several heuristics, based on separately solving each part of the problem, as well as a general integrated matheuristic. Our results and analysis not only compare solution costs but also highlight the value of an integrated approach.

■ HE-12
Thursday, 16:45-18:15 - 206B

Project management and scheduling

Stream: Timetabling and project management
Invited session
Chair: James Freeman

1 - The use of decision-dependent uncertainty sets in robust optimization: Modeling capabilities and solution approaches
Nikolaos H. Lappas, Anirudh Subramanyam, Chrysanthos E. Gounaris

Robust optimization is a systematic approach for mitigating the risk from parameter uncertainty in optimization models. Its main distinctive property is that it enforces the problem constraints for any realization of the uncertain parameters within the prescribed uncertainty set, which is typically defined as a constant set. In many cases, however, uncertainty can be affected by the decision maker's strategy (endogenous uncertainty). Motivated by this fact, we introduce broadly applicable decision-dependent polyhedral uncertainty sets, which allow us to capture functional changes in correlations induced by given decisions, as well as to eradicate conservatism eects from parameters that become irrelevant in view of the optimal decisions. The modeling capabilities afforded to us by using these new decision-dependent sets are illustrated in the context of various case studies that feature endogenous uncertainty, such as capacity expansion, offshore-oil planning, process scheduling, and clinical trial planning. Furthermore, we highlight the challenges associated with applying the standard, duality-based reformulation approach to solve robust optimization problems with decision-dependent sets, and we present a novel algorithmic solution approach based on the Kelley's cutting plane method in order to alleviate those.

2 - Prioritisation of project management capabilities: A software development application
James Freeman

The session is concerned with the relative importance of project management (PM) capabilities across a software project life cycle. Capabilities were matched to software tasks using an innovative web-based questionnaire survey of project managers working in the industry. Resultant data enabled key PM capabilities to be identified and categorized. Following on, a revealing breakdown by task allowed gaps between PM theory and practice to be achieved.

■ HE-13
Thursday, 16:45-18:15 - 207

Copositive and completely positive optimization

Stream: Copositive and conic optimization
Invited session
Chair: Peter Dickinson

1 - Considering copositivity locally
Peter Dickinson, Roland Hildebrand

In the study of convex optimisation problems it is useful to know the cone of feasible directions at a point. In this talk we characterise the cone of feasible directions for copositivity. This furnishes characterisations of the tangent cone, the minimal face and the minimal exposed face of the copositive cone at a matrix. All of the characterisations are in the form of sets of linear inequalities constructed from the (minimal) zeros of the matrix.

2 - SPN graphs: When copositive = SPN
Naomi Shaked-Monderer

A matrix is SPN if it is the sum of a symmetric nonnegative matrix and a real positive semidefinite one. Every SPN matrix is copositive, but the converse does not hold for matrices of order greater than 4. In this work we define an SPN graph to be a graph for which every copositive matrix realization is necessarily SPN, and consider the problem of characterizing such graphs. We present sufficient conditions for a graph to be SPN (in terms of its possible blocks) and necessary conditions for a graph to be SPN (in terms of forbidden subgraphs). We also discuss the remaining gap between these two sets of conditions.

3 - New upper bounds on the kissing number via copositive programming
Olga Kuryatnikova, Juan Vera

In this paper we build a hierarchy of upper bounds on the kissing number using copositive programming. Recently, it has been shown that the kissing number can be reformulated as an infinite dimensional optimization problem over the set of copositive kernels on a sphere. To obtain a new semidefinite hierarchy for the kissing number, we extend an existing sdp-based hierarchy for the finite dimensional copositive cone to the infinite dimensional case and exploit the symmetry of the sphere. Also, an alternative proof is given to characterize positive definite kernels invariant under automorphisms of the sphere with a given set of fixed points in terms of Jacobi polynomials.

■ HE-14

Thursday, 16:45-18:15 - 305

Combinatorial optimization 1

Stream: Combinatorial optimisation
Invited session
Chair: Rosiane deFreitas

1 - The 0-1 integer linearization property may be a powerful tool for Lagrangean relaxation
Monique Guignard-Spielberg, Renato de Matta, Jongwoo Park

The 0-1 Integer Linearization Property (ILP) characterizes some Lagrangean relaxation models (LRM). Used for instance by Geoffrion and McBride (1978), it can be exploited in several ways. The main idea is to introduce or keep in the Lagrangean model a set of constraints containing each a single 0-1 variable. These 0-1 variables must control non-overlapping subsets of the other variables. There may be constraints over the 0-1 variables alone. Ignoring these, the LRM decomposes into one submodel per 0-1 variable, which one solves with that variable set to 1, the optimum being the contribution of that variable at 1. Keeping only the 0-1 variables and their own constraints, one uses the contributions as coefficients in the LRM objective function, and solves a single 0-1 model whose optimum is the current LR bound. We present two important applications, one linear and one nonlinear. First a tile-manufacturing scheduling problem with changeover costs could be modeled so as to have the desired structure, yielding very strong LR bounds with only LPs to solve (de Matta, Guignard, 1994). Second, for some nonconvex quadratic assignment-type problems, it is possible to use an RLT-type linear model with the desired structure. The huge computational advantage is that the LRM still has the dimension of the original problem. In addition, for the CDAP, the bounds are of the same quality as RLT2 bounds (Guignard, 2006, Guignard and Park, 2016). We present corresponding computational results.

2 - The effect of metrics selection into solutions to the heterogeneous sector routing problem
Marcos José Negreiros, Augusto Palhano, Pablo Luis Fernandes, Nelson Maculan

This work consider the heterogeneous sector routing problem (HSRP) where a set of required links of a mixed graph drawn in the Euclidean space with known demands are to be assigned into a multiset of given sectors and circuits each with maximum quantity and capacity associated, in such a way it is necessary to minimize the total dispersion of the formed sectors and circuits. We here show the effect of using Euclidean and Manhattan metrics into street networks of real Brazilian cities over the final routes for the urban garbage collection problem by using a set of cluster-first route second and double cluster and route methodologies previously used for this propose. As result, the topology of the network show how the most appropriate one can affect the final routing costs for decision making.

3 - A multiobjective model to prevent and control child and adolescent obesity
Lorena Pradenas, Paul Bello

In this article we used the menu planning problem for generating nutritional menus to prevent and control child and adolescent obesity. A multiobjective mathematical model is proposed alongside a set of real instance varying in size. Small size instances were solved using the e-constraint method whereas more complex instances, in terms of the planning, were tackled using an evolutive algorithm. This problem is different than the Diet Problem (DP) in that it provides a high degree of detail in relation to the eating portions of each type of food, in each lunch time, and for different patients at every day planning. Then we have multiple combinations of foods available, nutrients, patient and times considered. An example of an achieved result is found, for the case of a girl aged 9-13 years and diagnosed with obesity. A three-dimensional representation of the solutions found is shown, using the constraint method belonging to the Pareto border approximation.

4 - Specialized algorithms for the binary knapsack problem
Víctor Parada

Automatically generated algorithms by genetic programming for a combinatorial optimization problem have as good computational performance as already existing constructive heuristics for the same problem. However, such algorithms lose effectiveness when faced with varied problem instances. In this article it is shown that classifying two-dimensional knapsack instances a priori, specialized and efficient algorithms are generated. Specifically, specialized algorithms find the optimal solution for most of the instances belonging to the same class.

■ HE-15

Thursday, 16:45-18:15 - 307A

Dynamic models and industrial organisation 2

Stream: Applications of dynamical models
Invited session
Chair: *Frank Steffen*
Chair: *Vladimir Shikhman*

1 - A Value-at-Risk (VaR)/Conditional Value-at-Risk (CVaR) approach to optimal train configuration and routing of hazardous materials (hazmat) shipments
S. Davod Hosseini, Manish Verma

Hazmat accidents rarely happen (low-probability incidents), but if they do occur then the consequences can be disastrous (high-consequence incidents). It is important to make a risk-averse route decision in hazmat transportation. Compared to the other existing approaches, VaR and CVaR produce a more flexible and reliable route modeling approach for hazmat transportation. Depending on the decision makers' attitude to risk, one can make multiple planning decisions according to each individual risk preferences. In addition, while most existing hazmat routing methods study the entire risk distribution, they focus more on the long tail to avoid extreme events. Our objective is to determine the optimal way to route hazmat railcars (along with regular railcars) between various origin-destination pairs using the available train services in the network, such that the transport risk measuring by VaR/CVaR is minimized. Note this implies not just a decision about the route but also the placement of hazmat railcars in a train (train configuration). We utilize freight-train derailment reports of the Federal Railroad Administration to take into consideration the characteristics of train accidents in railroad transportation of hazmat. This incorporates train-length, train-decile position of hazmat railcar, the sequence of events leading to hazmat release, and the associated consequence from ruptured railcars. The approach is finally used to study and analyze a US based case example.

2 - Tatonnements for Cobb-Douglas economy based on the power method

Vladimir Shikhman, Victor Ginsburgh, Yurii Nesterov

We consider the general economy with agents maximizing Cobb-Douglas utilities from the computational perspective. It is known that finding equilibrium prices reduces to an eigenvalue problem for a particularly structured stochastic matrix. We show that the power method for solving this eigenvalue problem can be interpreted as a natural tatonnement procedure executed by an auctioneer. Its rate of convergence is established under the reasonable assumption of pairwise connectivity w.r.t. goods within the submarkets. It is shown that the pairwise connectivity remains valid under sufficiently small perturbations of agents' tastes and endowments. Moreover, the property of pairwise connectivity holds for almost all Cobb-Douglas economies, i.e. in the regular case.

3 - Iterated sequential stability in the graph model for conflict resolution

Leandro Rêgo, France Oliveira

The Graph Model for Conflict Resolution (GMCR) is based on concepts of Game Theory and Conflict Analysis and is useful for describing and analyzing conflicts. The GMCR describes the set of decision makers (DMs) involved, the set of possible conflict resolutions, called states, and for each DM a directed graph, whose nodes are the states and the edges represent how the DM can switch from one state to another, and a preference relation over the set of states. Stability analysis is used in the GMCR to determine possible solutions for the conflict. Several solution concepts have been proposed which accommodate different DM's behavior. Some of them are: Nash, General Metarationality (GMR) and Sequential Stability (SEQ). For a state to be Nash stable for a DM, such DM cannot move to a more preferred state in a single step. For GMR and SEQ stability, while considering moving to a more preferred state, the DM foresees whether the opponent can react leading the conflict to a state not preferred to the current one. What differs SEQ from GMR is that, in SEQ the reaction of the opponent must also benefit him or her. However, we show by means of an example that there are situations in which to perform such reaction the opponent must be leaving a SEQ stable state for him or her, making it non-credible. In order to avoid that problem, we propose a new solution concept for the GMCR, called Iterated Sequential Stability, and explore its relation with other existing solution concepts.

4 - An efficient and truthful algorithm for fair scheduling on related machines

Ruini Qu, Bo Chen

With rapid expansion of traditional scheduling models to multi-agent systems, soliciting true system information owned privately by individual agents is fundamental in scheduling for system optimality. In this study, we are concerned with allocating a set of independent jobs to a number of related machines that are owned by self-interested agents in such a way that the allocation is as fair as possible (in terms of minimizing some Chebyshev distance to a virtually fairest allocation). The related machines differ only in their processing speeds, which are private information of the individual agents who own the machines and hence subject to misreports. Our challenge is to establish an allocation mechanism that is of high quality on all three objectives: (a) efficiency in allocating jobs, (b) truthfulness in soliciting private information of speeds and (c) optimality in achieving fairness. As a touchstone for the design of efficient algorithms for scheduling parallel machines, LPT (the largest-processing-time-first) heuristic has been attracting research attention since late 1960s. In this talk, we show that a modified LPT algorithm proposed in the literature is of high quality in fairness (c) in addition to its already recognized efficiency (a) and truthfulness (b).

■ HE-16

Thursday, 16:45-18:15 - 308A

Optimal control applications 1

Stream: Optimal control applications

Invited session

Chair: Richard Hartl

1 - Decisions on pricing, capacity investment, and introduction timing of new product generations in a durable-good monopoly

Andrea Seidl, Richard Hartl, Peter M. Kort

The aim of the present paper is to analyze how firms that sell durable goods should optimally combine continuous-time operational level planning with discrete decision making. In particular, a firm has to continuously adapt its capacity investments and sales strategy, but only at certain times it will introduce a new version of the durable good to the market. The launch of a new generation of the product attracts new customers. However, in order to be able to produce the new version, production facilities need to be adapted leading to a decrease of available production capacities. We find that that the price of a given generation of a product decreases over time. A firm should increase its production capacity most upon introduction of a new product. Then the stock of potential consumers is largest so that then the market is most profitable. The extent to which existing capacity can still be used in the production process for the next generation has a non-monotonic effect on the time when a new version of the product is introduced as well as on the capital stock level at that time.

2 - Capacity optimization for innovating firms

Rita Pimentel, Verena Hagspiel, Kuno Huisman, Peter M. Kort, Cláudia Nunes

In case of a product innovation the firms start producing a new product. While doing so, such a firm should decide what to do with their existing production process after the firm has innovated. Essentially it can choose between replacing the established production process by the new one, or keep on producing the established product so that it produces two products at the same time. Aim of this talk is to design a theoretical framework to analyze this problem. Due to technological progress the quality of the newest available technology, and thus the quality of the innovative product that can be produced by this technology, increases over time. The implication is that a later innovation enables the firm to produce a better innovative product. So, typically the firm faces the tradeoff between innovating fast that enlarges its payoff soon but only by a small amount, or innovating later that leads to a larger payoff increase, the drawback being that the firm is stuck with producing the established product for a longer time.

3 - Optimal control and the value of information for a stochastic epidemiological SIS-model

Vladimir Veliov, Peter Grandits, Univ. Ass. Dr. Raimund Kovacevic

We present a stochastic SIS-model of epidemic disease, where the recovery rate can be influenced by a decision maker. The problem of minimization of the expected aggregated economic losses due to infection and due to medication is considered. The resulting stochastic optimal control problem is investigated on two alternative assumptions about the information pattern. If a complete and exact measurement is always available, then the optimal control is sought in a state-feedback form for which the Hamilton-Jacobi-Bellman (H-J-B) equation is employed. If no state measurement is available at all, then the optimal control is sought in an open-loop form. Given at least an estimated initial probability density for the number of infected, the open loop problem can be reformulated as an optimal control problem for the associated Kolmogorov forward equation (describing the evolution of the probability density of the state). Optimality conditions are derived in both cases, which requires involvement of non-standard arguments due to the degeneracy of the involved H-J-B and Kolmogorov parabolic equations. The effect of the observations on the optimal performance is investigated theoretically and numerically.

■ HE-17

Thursday, 16:45-18:15 - 309A

Nonlinear optimization in the presence of uncertanties and parameters

Stream: Nonlinear optimization with uncertainties
Invited session
Chair: *Wil Schilders*

1 - Nonlinear optimization with parameters and parasitic effects
Wil Schilders

In this talk, we discuss the optimization of nonlinear electronic circuits. Analog designers start with the design of the so-called schematic, which is a connected graph of electronic components that satisfies the requirements and specifications of the customer. However, when this electronic circuit is manufactured and put on silicon, it turns out that the behavior is quite different from that of the original schematic. Parasitic effects play a major role: these can be substrate noise, or crosstalk in the interconnect system, or others. Often this means that the resulting manufactured system does not meet the specs of the customer, and hence a nonlinear optimization needs to be carried out, including parameters in so-called parameterized cells (P-cells), and taking care of the parasitic electromagnetic effects. As the calculation of the latter is rather time-consuming, methods need to be developed to make use of the result of previous iterations in the optimization process. We will discuss the ongoing work, and give an example.

2 - Robust optimization in nanoelectronics: A survey on results obtained in the NanoCOPS project.
Piotr Putek, Michael Günther, Evert Jan Willem ter Maten

Robust optimization of power devices to reduce hot spot areas, for example, has to include material and geometrical uncertainties, which have a direct impact on yield and performance. Hence UQ techniques have to be combined with direct optimization techniques. This talk will give a survey on techniques developed and applied to nanoelectronics problems, especially posed by the automotive industry, within the NanoCOPS project, which has merged the competence of mathematics and electrical engineering at academia with the expertise from semiconductor companies and specialized software house throughout Europe.

3 - Exploitation of random noise in simulated annealing
Fabian Bastin, Clément Bouttier, Clément Bouttier

Introduced by Kirkpatrick et al. in 1983, simulated annealing is one of the most popular algorithms for global optimization when the objective function is cheap to evaluate. It is still one of the most frequently used techniques in industry. It is, however, not adapted for noisy functions, as the acceptance mechanism creates a bias in presence of noise at low temperatures. Various authors, e.g. Gutjahr and Pflug in 1996, have shown that using mini-batch evaluation of increasing size in order to increase the precision when decreasing the temperature may extend the global convergence property of the simulated annealing to the noisy case. However, the proposed rates of increase result in expensive solution evaluations, making the simulated annealing algorithm inefficient compared with other metaheuristics and exact methods. In 1998, Fink suggested capitalizing on the noise to design an acceptance-rejection mechanism, and the approach was generalized in 2008 by Branke et al. They reported promising numerical results, but no convergence proof. In this talk, we review the proposed strategies exploiting the noise in simulated annealing and their impact on theoretical convergence. We then adapt the results obtained by Ceperley and Dewing in 1999 to efficiently exploit the noise while maintaining the convergence properties of the method. We illustrate the approach with simple numerical experiments and propose some extensions to the derivative-free optimization context.

■ HE-18

Thursday, 16:45-18:15 - 2101

Solution approaches in multiobjective optimization and application

Stream: Multiobjective optimization
Invited session
Chair: *Refail Kasimbeyli*
Chair: *Zehra Kamisli Ozturk*

1 - A two-objective aircraft maintenance routing problem
Gulnaz Bulbul, Refail Kasimbeyli

Aircraft maintenance routing is the third phase in airline operations planning and scheduling process, subsequent to flight scheduling and fleet assignment phases. The main concern of aircraft maintenance routing problem is determining a sequence of flight legs for an individual aircraft so that the maintenance requirements, which arise from regulations, are not violated. In this context, we propose a two-objective integer programming model where the objectives are maximizing the total connection value and minimizing the total ground time. Different scalarization methods are applied to scalarize the multiobjective mathematical model proposed. Finally, a new Lagrangian relaxation-based method is utilized to solve the scalarized problem.

2 - Smoothing of the conic scalarization method
Gurkan Ozturk, Refail Kasimbeyli

This paper studies the conic scalarization method for multi-objective optimization problems. The conic scalarization method uses special class of monotonically increasing sublinear functions. These functions consist of linear part augmented by a norm term. Due to the norm term, the zero sublevel set of these scalaraizing functions becomes a convex closed and pointed cone which contains the negative ordering cone. This property of the conic scalarizing functions allows to compute all properly efficient solutions of multi objective optimization problems without any kind of convexity and boundedness conditions. Another useful property of the conic scalarization method is that it allows to take into account the decision maker's preferences such as weights of objective functions and reference points. However, the norm term used in this method makes the function nonsmooth which leads to difficulties in the solution process. The aim of this work is to remove this nonsmoothness and to change the nonsmooth scalar problem to a smooth one by using additional continuous variables and functional constraints in the form of inequalities.

3 - Comparison of scalarization methods by solving a two-objective two-dimensional cutting stock and assortment problem
Banu İçmen, Refail Kasimbeyli

According to predefined demand list cutting smaller items from larger one or more dimensional stock materials, by minimizing the number of used stock or trim loss is described as a cutting stock problem. The assortment problem, also referred to as a stock size selection problem, involves the choice of the best combination of stock types to be maintained as inventory. In this work we consider two-dimensional two-stage guillotine cutting stock and assortment problems. We propose a two-objective integer-programming model in the form of simultaneously minimization of two objective functions, which are related to the total trim loss cost and the inventory cost respectively. By minimizing the number of used stock types we aim to decrease inventory cost. Different scalarization methods are used to solve the developed two-objective mixed-integer programming model and obtained solutions are compared.

4 - Novel solution approaches for multiobjective parallel machine scheduling
Zehra Kamisli Ozturk, Aseel Sabti

This talk considers the problem parallel machine scheduling with multi objectives. A new algorithm with the name Sequence Job Minimum Completion Time (SJMCT) is proposed for a set of independent jobs on non-identical parallel machines with aim of minimizing maximum job completion time and total tardiness when each job is assigned only to one machine at time. Also, the novel evaluative version of Non-dominated sorting genetic algorithm NSGA-II and Strength Pareto evolutionary algorithm SPEA-II, named (SJMCT-NSGA-II) and (SJMCT-SPEA-II) are improved to obtain Pareto optimal solutions. The simulation results are reported to show the efficiency of algorithms. Several tests are made with 80 jobs and 10 machines with different crossover probabilities, mutation probabilities and different generations with same size of the population to compare between two algorithms. The results demonstrate that the (SJMCT-SPEA-II) has better performed from the (SJMCT-NSGA-II). Besides, using Diversity Metric () which has been ensured this. Finally, the conclusions and some directions for future research are proposed.

■ HE-19

Thursday, 16:45-18:15 - 2102AB

Solving complex problems using data

Stream: Data driven modeling in operations management
Invited session
Chair: *Ola Eriksson*
Chair: *Hussein Danish*
Chair: *Soheil Sibdari*

1 - A data-driven optimization approach for three dimensional bin packing and mixed-case palletization
Paulo Carvalho, Samir Elhedhli

We propose a data-driven approach for mixed-case palletization and three dimensional bin packing problems based on analytics and optimization. The approach combines data analysis at the instance level to group items by common height, then uses the information to reduce the problem complexity. Both mathematical programming based methods and heuristics are proposed, allowing the solution of large problems in short computational times.

2 - A data analytics based approach to select input/output variables in DEA for predicting bank efficiency change
Imad Bou-Hamad, Abdel Latef Anouze

Data envelopment analysis (DEA) is a nonparametric method uses input and output variables to assess the relative efficiency of decision-making units (DMUs). The selection of these input/output variables is a crucial task and it is not straightforward. In baking sector, two common approaches are used for input/output variables selection, namely, operations and intermediation approaches. Other selection methods assume some expert knowledge with regard to the related output/input combinations particularly when having many potential variables. Researchers have proposed several methods for DEA input/output selection. Each method has its advantages and disadvantages. In this context, our study conducts an in-depth literature review to specify the most popular input/output variables in banking and introduces a data analytics approach for selecting input/output factors based on random forest. Additionally, we present a predictive framework to predict bank efficiency change. Our proposed methodology is illustrated with a sample of top 500 world banks.

3 - Machine learning delay predictors in multi-skill call center using real data
Mamadou Thiongane, Wyean Chan, Pierre L'Écuyer

We develop customer delay predictors for multi-skill call centers that take as inputs the queueing state upon arrival and the waiting time of the last customer served. Many predictors have been proposed and studied for the single queue system, but barely any predictor currently exists for the multi-skill case. We introduce two new predictors that use cubic regression splines and artificial neural networks,respectively, and whose parameters are optimized (or learned) from observation data obtained by simulation. In numerical experiments, our proposed predictors are much more accurate than a popular heuristic that uses, as a predictor, the delay of the last customer of the same type that started service.

4 - Parallel computing of logical analysis of data: A discrete optimization approach for pattern generation
Hussein Danish, Soumaya Yacout, Mohamed Ibrahim

Logical Analysis of Data (LAD) is a machine learning and pattern recognition approach for data analysis which combines concepts from optimization, combinatorics and Boolean functions. Lately, this approach has been gaining popularity because of its unique feature of finding interpretable patterns in order to characterize classes of observations. The interpretability of patterns proved to be an important feature for guiding the decision making process in some applications. In this presentation, we are specifically interested in engineering and industrial applications. Different techniques for pattern generation based on LAD approach have been proposed, for example the enumeration bottom up - top down, the mixed integer linear programming (MILP), and some heuristics such as the genetic algorithm. Due to the increase in the computational power of computers, as well as the ease of access to all types of sensors, which allow the collection of large volumes of data, the already existing LAD techniques for patterns' generation are becoming inadequate. In this presentation we show how Spark, an open-source cluster computing framework, has been used to speed up the computational capacity of LAD's pattern generation techniques. Examples, with comparisons between the computational time before and after the use of Spark, are given.

■ HE-20

Thursday, 16:45-18:15 - 2103

Dynamical models in sustainable development 3

Stream: Dynamical models in sustainable development
Invited session
Chair: *Chang Won Lee*

1 - Integration of MS / OR and GIS in smart cities
María del Mar Pino, José L. Pino

The global world in which we live these days is guided by changes and continuous movements. However, our municipal administration has not yet adapted to this profound change. Today there are multiple tools and a great technological potential to face the adaptation of the cities to the needs and improvements that the present demands us. This is where the Smart City concept appears, it becomes necessary to harmonize the great potential of the available data and techniques and the modern needs of techno-economic and social growth. One of the keys to the achievement of new models of cities is the development of an efficient and sustainable management of transport and traffic. Open

Data initiatives, such as sharing real-time information from the traffic counters, the availability of parking spaces or public bicycle systems, are increasing sources of information. The objective of this work is to show an example of useful integration of web scraping, social network analysis, optimization methods and Geographic Information Systems, in the analysis of hourly and weekly patterns, seasonal variations, influence of main meteorological components (temperature, atmospheric pressure, wind, humidity, precipitation and cloudiness) and the incorporation of this information in the optimization of urban traffic and vehicle-sharing fleet in some Spanish cities.

2 - Humanitarian supply chain management: Concepts, current trends, and emerging paradigms
Chang Won Lee, Gary Gaukler

In this study we explore the field of Humanitarian Supply Chain Management(HSCM). Even though HSCM is a topic of practical urgency, theory-grounded research is still in its early stages. We expand the understanding of HSCM by identifying and synthesizing existing HSCM concepts; systematically reviewing current trends and existing literature; and defining an HSCM research framework that reflects new directions as well as emerging paradigms. Our study primarily aims to contribute to the theory of HSCM, but also has practical relevance through exploring case studies and benchmarking of practical applications of HSCM.

■ HE-21

Thursday, 16:45-18:15 - 2104A

Cutting and Packing 5

Stream: Cutting and packing
Invited session
Chair: Carlos Lamas-Fernandez

1 - A fit-degree based greedy scheduling for the 4D space-time optimization problem
Yan Jin, Yue Yang, Kun He

We propose an efficient scheduling algorithm for the four-dimensional space-time optimization problem (4D-STO). 4D-STO is one of the hardest combinatorial optimization problems proposed by Huang and He in 2013. It involves a series of NP-hard 3D-RPPs (Rectangular Packing Problems) for the whole scheduling period. Also, 4D-STO can degenerate to the 4D-SPP (Strip Packing Problem) by regarding the processing time of each box as the fourth space dimension. 4D-STO has wide applications in the area of vehicle routing, multi-site container loading, warehouse arrangement, and temporal task allocation. To our knowledge, there is no practical algorithm or benchmark in the literature for this recently proposed problem. Hereby, we propose the first practical algorithm for solving the 4D-STO - an efficient Fit-degree based Greedy Scheduling algorithm (FGS). FGS is composed of a dedicated evaluation function with the fit degree to evaluate the candidate placements when packing the boxes into the container, and a heuristic strategy to rearrange the location and orientation of the boxes already placed in the container over time. We also present data for the 4D-STO problem instances to encourage further research and greater comparison between our FGS and future algorithms. Besides, we employ an additional experiment to show the effectiveness of the 4D-STO model when comparing with the 4D-SPP.

2 - Globally optimized finite packings of arbitrary size spheres in Rd
Janos D. Pinter, Frank Kampas, Ignacio Castillo

Given a finite collection of d-dimensional spheres with arbitrarily chosen radii, our objective is to find the smallest sphere in Rd (d>=2) that contains the entire collection of these spheres in a non-overlapping arrangement. Generally speaking, analytical solution approaches cannot be expected to apply to this problem-type, except for very small or certain specially structured sphere configurations. In order to find high-quality numerical (approximate) solutions, we propose a suitable combination of heuristic strategies with constrained global and local nonlinear optimization. We present numerical results for non-trivial model instance-classes of optimized sphere configurations with up to n = 50 spheres in dimensions d = 2,3,4. Our numerical results for an intensively studied model-class in R2 are on average within 1% of the entire set of best known results, with new optimized (conjectured) packing results for previously unexplored generalizations of the same model-class in R3 and R4. The results obtained support the estimation of the optimized container sphere radii and of the packing fraction as functions of the model instance parameters n and 1/n, respectively.

3 - A meta-heuristic technique for the packing of three-dimensional irregular pieces
Carlos Lamas-Fernandez, Julia Bennell, Antonio Martinez Sykora

In this work we address the 3D irregular open dimension problem. This problem consists in placing a set of arbitrarily shaped irregular pieces in a container of a fixed base and variable height. The objective is to minimise the height of the container. We represent the geometry of the pieces by voxels, the three-dimensional equivalent of pixels. In this discretised space, we define the no-fit voxel. This is an extension of the two-dimensional no-fit polygon, a very popular tool used in two-dimensional packing. The no-fit voxel can be pre-calculated and allows us to very quickly evaluate intersections of pieces during the algorithms. Using this tool, we propose a meta-heuristic algorithm that allows overlap of pieces in its intermediate steps. It consists of two components, a search phase and strategic oscillation. In the search phase we perform a number of piece movements and swaps with the aim of resolving the overlap and finding feasible solutions. In the strategic oscillation, we increase or reduce the height of the container depending on the status of the layout. We test this technique across a range of different instances. Some are adapted from existing literature and some are shapes randomly generated by ourselves by adapting 2D image generation algorithms. Our results show that this is a robust technique that can be successfully applied to find dense packings of sets of pieces with very different features, including realistic models of 3D printed objects.

■ HE-22

Thursday, 16:45-18:15 - 2104B

Applications in telecommunications, energy and biology

Stream: Discrete optimization, mixed integer programming (contributed)
Contributed session
Chair: Agnès Plateau

1 - A mixed-integer linear programming model for biomass terminal operations
Ioannis Dafnomilis, Dingena Schott, Mark Duinkerken, Gabriel Lodewijks

Northwest Europe is expected to import increasing amounts of biomass by 2030, to the range of 18-60Mt, mostly in the form of wood pellets. To optimize handling procedures, the equipment and techniques at the import terminals need to cope with the biofuels' properties. Dedicated equipment and additional procedures increase the complexity of biomass terminal operations and, consequently, the logistics associated with them. The objective of this work is to determine the configuration of equipment that minimizes the total costs incurred during biomass terminal operations. Each operational step on a terminal can be completed by numerous different types of equipment and between some steps equipment can be shared. Different equipment types are associated with specific operational capacities and certain capital and operational expenses. A mixed integer linear programming model has been developed in order to optimize a dedicated biomass terminal's equipment configuration. As input, real data associated with terminal operations are used in order to assess the efficiency of the model under a given throughput scenario. The model will later be used in connection with various developed scenarios regarding biomass import projections to 2030 and beyond, with the intention of ascertaining the most efficient terminal setup to handle incoming biomass volumes.

2 - MILP formulations and branch & cut for the min-up/min-down unit commitment problem
Cécile Rottner, Pascale Bendotti, Pierre Fouilhoux

The Min-up/min-down Unit Commitment Problem (MUCP) is to find a minimum-cost production plan on a discrete time horizon for a set of fossil-fuel units for electricity production. At each time period, the total production has to meet a forecasted demand. Each unit must satisfy minimum up-time and down-time constraints besides featuring production and start-up costs. We compare two MILP formulations for the MUCP. A first possibility is the classical MILP formulation which is a generalization of the 1-unit formulation proposed by Rajan and Takriti. We introduce an alternative flow based formulation on a particular graph. We prove the linear relaxations of both formulations are equal. Some polyhedral aspects of the MUCP with multiple production units are analyzed on the basis of the first formulation. The canonical inequalities of the knapsack polytope are translated to obtain the so-called up-set inequalities for the MUCP polytope. A large class of inequalities, called interval up-set inequalities, is also introduced, generalizing both up-set inequalities and minimum up-time inequalities. Finally an efficient Branch & Cut algorithm is derived using up-set and interval up-set inequalities.

3 - An integer programming approach to stem cell culture problem
Jongyoon Park, Kyungsik Lee

Stem cell therapy product is made from adult stem cell and can be used to treat many diseases including cardiac disease, nervous system disease, etc. Due to the long culture period and limited capacity of incubators, we need to optimize the schedule of stem cell culture to better utilize the production capacity. In this paper, we consider stem cell culture problem to maximize the number of completed culture order during given period under the capacity constraint and the lot covering constraint arising from the unique characteristics of the stem cell culture process. We present a decomposition approach for the problem. Preliminary computational results also will be given.

4 - Comparison of mixed integer programming fromulations for the minimum connected coverage problem
Agnès Plateau, Sourour Elloumi

In the context of wireless sensor network, the Minimum Connected Coverage (MCC) problem consists in locating a minimum number of sensors such that the whole target field is covered, and every placed sensor can transmit its data to a base station. We introduce and study several mixed integer linear programming formulations for the MCC problem. We compare their LP-relaxation bounds and deduce some dual bounds from LP duality. Then, through computational experiments on graph instances, we compare the practical ability of our MILP models in solving the MCC problem. More precisely, we provide the LP-bounds yielded by our mathematical programming formulations at the root of the branch- and-cut process as well as the proportion of solved instances, the CPU computation time and the number of explored nodes in the tree search.

■ HE-23

Thursday, 16:45-18:15 - 2105

Transit optimization

Stream: Optimization for public transport
Invited session
Chair: Ka Yu Lee

1 - The limited-stop bus service design problem with stochastic passenger assignment
Homero Larrain, Juan Carlos Muñoz

Limited-stop services, which serve a subset of the stops along a corridor, can simultaneously improve the level of service and the cost efficiency of transit corridors when properly designed. In this work, we introduce a methodology for designing limited-stop services by separating the problem into a frequency optimization problem and a passenger assignment problem. The advantages of this approach are twofold. First, it allows the implementation of a bi-level solution algorithm, which accelerates the solution of the problem, particularly when bus capacity is constraining. Second, it allows accounting for stochastic user behavior. This kind of behavior, which had not been used in the design problem before, is more realistic, and provides more robust and reliable solutions. Our methodology was tested on nine scenarios, based on real-world corridors such as Caracas Av. in Bogotá. Our experiments show that this new methodology yields solutions for the deterministic case significantly faster than an existing benchmark algorithm. We also show that the deterministic passenger behavior assumption can lead to overcrowding if passengers really behave in a stochastic manner, which is arguably more likely to happen in practice, demonstrating the importance of a design tool such as the one we introduce in this work.

2 - New results of a technology choice model for a transit line
Luigi Moccia, Duncan W. Allen, Eric C. Bruun

We present results of a new technology choice model that minimizes the sum of passenger and operator costs of a transit line. The new model expands a previous one (Moccia and Laporte, 2016) in five directions. First, it improves by multiple periods the representation of the demand distribution along the service hours in a year. Second, it proposes a new penalty function for crowding that reduces the underestimation inherent in a synthetic estimation through average vehicle occupancy rate. Third, it considers frequency-dependent intersection delays. Fourth, it introduces a self-calibrating maximum frequency. Fifth, it presents a more refined representation of capital, operation, and maintenance costs. On the practical side, we provide a deep analysis of techno-economical parameters of two semirapid technologies, namely bus rapid transit (BRT), and light rail transit (LRT). We examine scenarios offering comparable performance by both technologies in terms of service, rather than assuming that service quality is strongly associated with technology. These scenarios differ in performance levels, and, as a result, in productive capacity (Vuchic, 2007).

3 - An analytical model for comparison of demand responsive and fixed route transit systems
Daisuke Hasegawa, Tsutomu Suzuki

Local transit systems are categorized into two types: fixed-route transit (FRT) and demand responsive transit (DRT). FRT such as bus or tram has fixed routes and requires both access and egress time of passengers and vehicle travel time between the nearest stations of origin and destination. DRT such as Dial-a-Ride system or ride share service requires only vehicle travel time on the direct connection between the origin and destination, and can change routes flexibly corresponding to requests of passengers. However, detours of vehicles to correspond to dispersed demand points sometimes can cause a decline of level of service (LOS) in DRT. The aim of this study is to clarify how the appropriate transit type changes according to density and travel impedance of passengers by comparing the LOS of FRT and DRT using an analytical model. The model evaluates LOS by the sum of waiting and travel time of passengers in a continuous space with a uniform density of passenger under different budget constraints. Results show that DRT with low budget is appropriate transit system for areas with low density and high travel impedance, while FRT with high budget shows the advantage in areas with high density and low travel impedance. Furthermore, as budget increase, detour travels of DRT decreases by increasing the number of vehicles, and it leads to the improvement of LOS in DRT.

4 - Spatial-temporal speed analysis for the estimation of origin-destination matrix
Ka Yu Lee, Jean-Marie Freche, Pascale Kuntz, Fabien Lehuédé

The origin-destination matrix serves as an important reference for improving public transport offers. Its generation using surveys or smart card systems is often time-consuming and costly, imposing challenges on emerging economies. We propose a methodology to substitute part of the surveying effort by an analysis of spatio-temporal characteristics captured in AVL data or GPS traces. Statistical learning methods are applied for the exploration and analysis of vehicle speed. Passenger counts at strategic locations are then used to parametrize the models and estimate the local demand for transport. Through a reverse assignment process, we derive an approximation of the time-dependent origin-destination matrix. Models and first results obtained using field-collected data will be presented.

■ HE-24

Thursday, 16:45-18:15 - 301A

Optimisation and simulation for patient scheduling

Stream: CORS SIG on healthcare
Invited session
Chair: Louis-Martin Rousseau
Chair: *Nadia Lahrichi*

1 - Chemotherapy outpatient scheduling problem - A practical case
Menel Benzaid, Nadia Lahrichi, Louis-Martin Rousseau

Chemotherapy Scheduling Problems have been getting more and more attention. While most researchers have focused on solving a Makespan Minimization Problem, other variations consider earliness and tardiness penalties, the cyclic nature of treatment plans, and resources constraints. Very few studied the uncertainties that appear on arrival time, cancellations, treatments duration, and same day add-ons. Although, progress has been made, Chemotherapy Appointment Scheduling Systems employed to manage access to care services in practice are still very much reliant on the experience level of scheduling staff. Moreover, this approach limits the potentials on how much extra capacity can be added to the system. Therefore, opportunities for learning and advancements in this area of research are multiple. In this project, we study the practical case of the Outpatient Oncology Center of Notre-Dame Hospital in Montreal. Observations have been made to extricate which elements of the real process (cyclic nature of treatment plans, variability in resource requirements, patient characteristics, uncertainty due to cancellations, arrival time, add-ons, treatments duration, staff satisfaction) need to be integrated in a mathematical model which includes workload features to solve this Problem. We focus on determining the best scheduling for patients in order to allow chemotherapy caregivers to add extra capacity without compromising on staff satisfaction, and on the quality of care offered.

2 - Modeling and optimization of patient flows in radiotherapy centers
Yosra El Abed, Nadia Lahrichi, Louis-Martin Rousseau

Like most healthcare institutions, radiotherapy centers are confronted to several challenges such as the management of the excessive wait times for patients and the coordination of resources within the institution. Priorities for cancer patients are established by the ministry and additional requirements are provided by each institution to maintain high service levels. These grids are strict in terms of deadlines and priorities and the compliance with these rules is very complex. The centers must then opt for management strategies that ensure, on the one hand, the high level of care provided to patients (in terms of quality and time) and on the other hand, the optimal use of available resources. To do this, we develop a flow simulation platform that model several trajectories of patients as well as their interactions with the resources in the radiotherapy center. In the first phase of this work, a standardized process modeling language " Business Process Model and Notation " was used to develop a model to better understand the patient's path and trajectory. In the second phase, this model was reproduced with the java programming language and implemented in the simulator to simulate the flows and to evaluate several management strategies. We have used two practical cases the Centre Intégré de Cancérologie de Laval and the radiotherapy center of Hospital Notre-Dame, to better understand the processes in place and validate the simulator.

3 - Patient classification for appointment scheduling in ambulatory clinics.
Dina Ben Tayeb, Nadia Lahrichi, Louis-Martin Rousseau

The problem of access to medical care in most developed countries has become a concern in recent years. One of the most important components influencing access is the patient's waiting time for an appointment. It is considered a key factor for patient satisfaction. In order to improve health care performance and reduce patient waiting times, it is important to consider interactions between resource capacity, service time and appointment scheduling rules. The main objective of our work is to set up a patient appointment scheduling algorithm for an imaging center to increase the number of patients seen per day, while we minimize the waiting times and optimize the material and human resources. The good quality of service will be maintained. The project uses machine learning techniques to estimate the time required to complete each type of examination and possibly to classify patients. Using predictive models, we develop an online stochastic model to determine the day and the best possible time slots for each appointment. At the end of our project, we will be able to assign to each patient the best appointment time, having the most positive impact on the increase of the number of patients during the day.

■ HE-26

Thursday, 16:45-18:15 - 302A

OR in agriculture 2

Stream: OR in agriculture
Invited session
Chair: Marina Segura

1 - Market imperfections and income concentration: Global and regional perspectives on Brazilian agricultural production performance
Geraldo Souza, Eliane Gomes, Eliseu Alves

We measure performance for the Brazilian agriculture by means of free disposal hull (FDH) measures of technical efficiency. Measurements are conditional on contextual variables that may be responsible for market imperfection variables. The production frontier is generated by a product probability measure. Production observations are aggregated by county and analyzed by region. The efficiency measure is output oriented and assumes variable returns to scale. Output is rural gross income and inputs are land expenses, labor expenses and expenses on other technological inputs. The covariates for production are credit, technical assistance, social, environmental, and demographic indicators and income concentration, measured by the Gini index. Overall Brazilian rural production performance responds favorably to credit, income concentration and environment score and unfavorably to technical assistance, at the 95% level. Results differ by region. Agricultural public policies envisaging inclusion of small farmers into the main stream of production should be regionally oriented.

2 - Information quality value under a real option planning approach: The case of wine grape harvesting
Elbio Avanzini, Alejandro Mac Cawley, Jorge Vera, Sergio Maturana

Planning in the agriculture is subject to a significant level of uncertainty due to the climatic and biological factors involved in the production. In this work we study, using a real option approach, how climatic information quality or certainty affects the harvesting decisions in wine grape production system. The proposed model, as the grape producer, has to determine a harvesting plan (lots to harvest, labor and machine) at the start of the vintage. This harvesting plan is then confronted with climatic conditions, such as rain, which affects it by not allowing harvest during that period. In order to take account for the probability of rain in a given moment, we model the its probability using binomial lattice model and plan using a real option approach. The climatic information quality or certainty is modeled as the difference between the "real" probabilities and the "projected" ones during the planning phase. The effect is measured as the differences in the value of the plan under the different circumstances (high or low uncertainty). The contribution of this work is to develop a methodology that will allow the decision maker to determine the value and effect that information certainty has on the quality of the planning, under a real option planning approach.

■ HE-27

Thursday, 16:45-18:15 - 302B

Advances in mine planning 1

Stream: OR in mining
Invited session
Chair: Michel Gamache

1 - A two-stage stochastic model for open pit mine planning under geological uncertainty
Eduardo Moreno, Xavier Emery, Marcos Goycoolea, Nelson Morales, Gonzalo Nelis

In open pit mining operations, planners must periodically prepare an strategic mine plan. This is a production schedule for the remaining life of the mine based on the information of a block models. Block models usually include a single estimation of the geological characteristics of the rock, particularly ore grades. However, most of block-models are constructed by averaging conditional simulations of the mine, based on the information from drill-holes. In this work, we present a two-stage stochastic model for this problem, that consider the different simulations of an ore body. In a first stage, the scheduling decision is taken, assigning an extraction period of each region of the mine. In a second stage, when the true ore grade is revealed, the model decides how to treat each individual block. Our proposed integer programming model can be reformulated as a large-scale precedence constrained knapsack problem, that can be (near-optimally) solved using decomposition techniques. This allow to solve real instances of the problem in a few hours. We apply this model to a copper mine in Chile. We compare the resulting NPV from the deterministic solution (expected value solution), the best-possible plan for each scenario (wait-and-see solution), and our proposed model. Computational experiment shows that, in these data, the proposed two-stage stochastic model captures a 70% of the gap in between the wait-and-see and the deterministic solution, obtaining more robust mine plans.

2 - Investigating a new hyper-heuristic method for mine production scheduling under uncertainty
Amina Lamghari, Roussos Dimitrakopoulos

A hyper-heuristic refers to a search method or a learning mechanism for selecting or generating heuristics to solve computational search problems. Operating at a level of abstraction above that of a meta-heuristic, it can be seen as an algorithm that tries to find an appropriate solution method at a given decision point rather than a solution. In this talk, a new hyper-heuristic that combines elements from reinforcement learning and tabu search is presented. It is applied to solve a complex real-world scheduling problem, namely the stochastic open-pit mine production scheduling problem with metal uncertainty (SOPMPSP). The performance of the new hyper-heuristic is assessed by comparing it to several solution methods from the literature: problem-specific algorithms tailored for the SOPMPSP and general hyper-heuristics, which use only limited problem-specific information.

3 - A mixed-integer programming model for an in-pit crusher conveyor location problem
Carlos Andres Jimenez Builes, Michel Gamache

Haulage costs account for around a half of the total operating costs in large open-pit mines. One way to reduce the haulage costs is to shorten the haulage distances by bringing the truck dump point closer or even into the mine. There is a tendency in the direction of the high speed, large capacity conveyor systems, and these arrangements have been very productive. Conveying and truck-shovel systems compared to conventional truck-shovel systems alone, provide operating cost efficiency and high reliability of in-pit crushing, making those types of systems more appealing to be implemented in modern mining activities. The main elements to be considered in mine planning to implement an in-pit crusher system are conveyor layout and crusher position. This paper aims to solve the location problem of an in-pit crusher conveyor system through the use of a dynamic uncapacitated facility location problem, considering operative and financial parameters and mine plan scheduling. The methodology was constructed for locating the in-pit crusher equipment and conveyor layout for an iron mine project. The results are applicable for considering certain conditions related to geology, pit geometry and transport distances.

4 - Optimizing truck dispatching decisions in open-pit mining using integer programming
Amanda G Smith, Jeff Linderoth, James Luedtke

We present a novel approach to the open-pit mining truck-dispatching problem that employs mixed-integer programming (MIP). The truck-dispatching problem seeks to determine how trucks should be routed through the mine as they become available. Among the challenges of the dispatching problem is the need to make decisions in real-time for the constantly changing system. In addition, the dispatching problem attempts to balance the distinct (and potentially competing) objectives of meeting production targets and maintaining grade targets at the processing sites. Existing literature focuses on strategic planning in open-pit mining and heuristic solutions to the dispatching problem (Temeng, 1998; White, 1991). We propose an optimization-driven approach to solving the dispatching problem in the form of a MIP model. The model is difficult to solve directly within time constraints due to its large size. Therefore, we propose heuristic algorithms to quickly produce high quality feasible solutions to the model. We conclude by presenting computational results demonstrating the effectiveness of the proposed heuristics.

■ HE-28

Thursday, 16:45-18:15 - 303A

Applications of OR 5

Stream: Applications of OR (contributed)
Contributed session
Chair: Gang Du

1 - On the optimization of broadband beamformer configurations
Cedric Yiu

In signal enhancement, beamforming techniques play a significant role when a number of sensors are deployed in the applications. The required signal located in a particular area is enhanced via spatial filtering. The design of broadband beamforming systems can be formulated as an optimization problem. In the literature, various methods have been applied to optimize on the filter coefficients. In addition, we found that the geometric configuration of the array is also very important for the accuracy of the designs. In view of this, the microphone locations can be optimized together with the filter coefficients and the overall problem is formulated as a nonconvex optimization problem. This problem is addressed here. The optimization problem will be described and the complexity of the designs will be considered. The proposed method will be illustrated by several design examples.

2 - A joint optimization model for coordinated value activities configuration and decisions of cold chain logistics
Gang Du, Shanshan Meng, Yixuan Xiong

Based on the main value activities in cold chain logistics enterprises: storage, processing and delivery, a market demand-oriented 0-1 nonlinear bilevel programming model of joint optimization for coordinated value activities configuration and decisions is established in this paper. In the upper level of the model, the objective function is the maximization of the ratio of customer utility to total cost, the decision variables are the configuration choices of value activities and the constraints are mainly from the scope of configuration choices. In the lower level of the model, the objective function is the minimization the total cost corresponding to the configuration in the upper level, the decision variables are the coordinative activities plan choices and the constraints are mainly the demands of internal each activity and external cooperation among activities. When the configuration is determined in the upper level, the lower level will become a block diagonal structure optimization model. A calculating procedure is given by using genetic algorithm. A demonstration calculation based on a Chinese local cold-chain logistics enterprise L company is done as a case study.

3 - Incorporating frequency response into unit commitment formulation and non-convex pricing of inertia service
Ehsan Davari Nejad, Mohammad Reza Hesamzadeh

We study a market approach towards the frequency response (FR) problem of energy systems and in particular, inertia adequacy. We have developed a mathematical formulation to integrate FR in unit commitment (UC) problem. The proposed UC is a mixed-integer linear programming problem (MINLP), since it includes binary decision variables and also non-linear constraints which are expressed in terms of differential equations. We have employed mathematical techniques to transfer from a MINLP to a LP problem. To obtain the marginal prices from this non-convex optimization model, we have proposed the following methodologies. In the first method (Restricted Model), the MILP is solved with a GAMS solver and then based on the obtained solution, the binary variables are fixed to their optimal values and treated as real variables in the new problem. In the second method (Semi-Lagrangian or Fully Dispatchable Model), the MILP is linearized through relaxing the integer variables and allowing them to get values between zero and one. In reality this assumption is not true. However, it results in lower uplift payments in some cases. Investigating deeper this issue, we will study the total profit of each generating units. Therefore, based on the results for profits, there are some negative numbers among the amounts for profits. This simply means that some units are not finding it reasonable to stay in this market any longer. Different uplift payment methods have also been investigated.

■ HE-29

Thursday, 16:45-18:15 - 303B

Behavioural economics for energy and environmental challenges

Stream: Long term planning in energy, environment and climate
Invited session
Chair: *Sandrine Selosse*
Chair: *Ankinée Kirakozian*
Chair: *Christophe Charlier*

1 - Nudging electricity consumption within firms. Feedbacks from a field experiment
Christophe Charlier, Ankinée Kirakozian, Gilles Guerassimoff, Sandrine Selosse

Energy consumption is a serious environmental issue due to global warming and pollution. Public policies are developed in this context. Behavioral economics pays particular attention to the use of nudges. A nudge is a form of policy aimed at changing individual behaviors without using financial incentives or order, for example by providing information to individuals so as to conduct behaviors in the direction desired by the policy-maker. Interestingly "private nudges" can be imagined for companies. Many economists and psychologists have studied the impact of nudges on households' proenvironmental behaviors. Yet, studies focusing on nudging employees' energy use are rare. The objective of our paper is precisely to test the effect of 3 nudges on employees' energy consumption with the help of a field experiment. The first nudge alerts individuals on good energy consumption practices. The second one stresses the responsible use of energy regarding environmental stakes. Finally, a "social comparison" nudge is used informing employees on others' energy consumption in firms participating to the experiment. The field experiment is conducted with 50 French companies' sites. These companies are equipped with "Building Management System", allowing obtaining a daily electricity consumption. The experiment is conducted over 12. The data collected are subjected to statistical and econometric processing allowing us determining the impact of the various nudges tested.

2 - Bad, for the greater (public) good: Third-party monitoring and sanction on pro-environmental behavior
Ankinée Kirakozian, Agrès Festre, Pierre Garrouste, Mira Toumi

It is well recognized that incentives can influence the cooperation of individuals in providing public goods. The aim of this study is to experimentally adapt a Public Good Game (PGG) to the environmental issue of waste management. We report an experiment in which players have to cooperate in order to reduce the cost of waste sorting treatment. Bisides the traditional PGG, a third-party player (Advisor) is introduced in each group in the incentivized treatments. The third party has the possibility to provide a recommendation on the desirable individual contribution (Treatment 1), or collectively punish the non-cooperative behaviors by increasing the tax rate (Treatment 2). Furthermore, participants perform an effort task to increase their given initial endowments, and a measure of social preferences through a Social Value Orientation test (SVO). We find that both the advice and the threat of sanction increase significantly the average level of individual contributions. However, we see that once the sanction is applied, it ha no significant effect in increasing cooperation, but on the contrary decreased it. Moreover, we find in line results on altruism hypothesis that high income individuals contribute more in absolute value compared to low income ones Becker (1974).

3 - Tools for the improvement of households energy management
Gilles Guerassimoff

Energy consumption in tertiary and residential sector is one of the biggest parts of the total with more than 40%. With the new regulation in building construction we are able to produce buildings producing energy instead of consuming it. However, the appliances level in households is increasing a lot and the level of energy consumption of these objects becomes the major energy consumption of a household. Some experiments have been tested to assess the efficiency of several tools for different actions. On one hand we can inform people of their energy behavior and try to change their habits in a positive way of a reduction of their consumption. To provide such tools, it is important to provide and to collect the right information in order to give a dedicate message in each situation. To fulfill this point it is important to include some sociological consideration in the analyses of the data. Other ongoing experiments try to analyse by several statistical and machine learning techniques a rich survey of an important sample of population to establish some profiles and help the household in their energy consumption reduction. This presentation will introduce the two approaches with some results and way of progress.

■ HE-30

Thursday, 16:45-18:15 - 304A

OR on migration and refugee issues

Stream: Sustainable living: Cognitive, social, economical, ecological and world view
Panel session
Chair: *Ulrike Reisach*
Chair: *Gerhard-Wilhelm Weber*

1 - Information media and migration: Channels, content and culture
Ulrike Reisach

Increasing numbers of refugees and migrants from crisis regions and developing countries are seeking asylum and better lives in developed countries. Most of them follow their own sources and networks and have little knowledge about their destinations. Government agencies and NGOs in the target countries are running information platforms and campaigns, trying to inform them about admission criteria and life and work in industrialized countries. Despite increasing efforts to send appropriate messages, many platforms and apps fail in reaching their intentions and target groups. The quality of information media provided by developed countries has been systematically evaluated by Prof. Dr. Ulrike Reisach and her research team at Neu-Ulm University of Applied Sciences in Germany between mid-2015 and 2016. They developed an assessment scheme for the challenge and searched for online and offline information and teaching material, platforms and applications designed for asylum seekers and migrants. Information resources from typical target countries were compared and evaluated to find best practices and complementary material which could potentially be shared or used by more than one country. Along with the testing and interviews with asylum seekers, social workers, teachers and representatives from the countries of origin, they revealed stunning contrasts and between communication and information/media usage patterns of refugees/migrants and those who try to inform them.

2 - Labor market inclusion: Experiences and case studies from Germany 2016
Ulrike Reisach

After more than a million new arrivals of refugees and migrants in 2015, Germany has been facing the huge task of labor market integration of a broad variety of people, some with good educational backgrounds, some with low or no formal qualification and some illiterate. In interviews with representatives from companies, education ministries, schools, social workers, consultants, volunteer helpers, and asylum seekers, Prof. Dr. Ulrike Reisach and her team have identified some of the major challenges of both sides as well as approaches which seem to be more successful than others. In her contribution for the conference she will offer well-structured insights into the manifold dimensions and of the task for the civil society as well as for businesses and administrations. Based on interviews and a structured assessment of the communication and teaching efforts of the institutions involved, Prof. Reisach and her research team discovered a few decisive factors which support or slow down the process of inclusion. Among the positive factors are intercultural competencies and a deep understanding of the process of forwarding knowledge in the respective culture. This comprises understanding media usage as well as the region of origin's traditions of schooling, teaching and learning as well as those regarding job search, application and HR development at the workplace. In the research, it turned out that companies and placement agencies which already had a diverse workforce and deep intercultural experience were more successful in developing appropriate programs than others. Nevertheless, some smaller local employers were also successful with personalized inclusion efforts. The contribution will explain how framework conditions and processes in the civil society, including coalitions of employers, chambers of industry and commerce, local schools, work placement agencies, social workers, NGOs and volunteers, positively supported integrative efforts and which assumptions and attempts turned out to be less conductive. Prof. Dr. Ulrike Reisach teaches Intercultural Management and Intercultural Communication at Neu-Ulm University of Applied Sciences in Bavaria, Germany. Together with her 7th semester students and several external experts, she has conducted a non-profit research project on information media for refugees and migrants between mid-2015 and December 2016.

■ HE-31

Thursday, 16:45-18:15 - 304B

Sports scheduling

Stream: OR in sports
Invited session
Chair: *Mario Guajardo*

1 - Referee assignment in the Argentinean basketball league
Mario Guajardo, Guillermo Durán, Facundo Gutiérrez

We develop an integer programming approach to assign referees to the matches of the main basketball league of Argentina. The goal is to minimize the total travel cost of the referees, while also taking into account other aspects, such as referee categories, minimum/maximum number of refereed matches, referee-team balance, and maximum number of travel days. Numerical results obtained using real-world data from past tournaments show considerable reduction in travel distances and costs, in the order of 25 to 30%. Our approach is currently being used by the league to assign referees in the 2016-17 season.

2 - Professional football tournament scheduling in Norway
Lukas Bach, Tomas Eric Nordlander

For professional sport federations, tournament schedules affect a variety of stakeholders (teams, television networks, fans, communities). The quality of such schedules affects the revenue of the teams (and federations themselves), as television networks are willing to pay higher broadcasting rights depending on whether the schedule meets certain requirements (e.g. games that draw larger audiences are scheduled on attractive dates). Fans often also decide whether to buy tickets based on similar reasons. Improved scheduling boosts attendance and generates a positive effect on the local economy. The Norwegian professional football league that we schedule is a double round robin tournament, i.e., a tournament where all teams meet each other once at home and away. To satisfy the stakeholders and thereby create better schedules we use a mixed integer programming model to schedule the top professional Norwegian football league. To solve this model it is necessary to decompose it into two parts. The approach applied is, at the first stage, assigning teams to a home / away pattern. In the second stage, we assign games to the individual rounds. All this subject to a set of home / away wishes from the clubs, game specific requirements from TV and the Norwegian football federation. By solving this problem, we are successfully able to get an optimised schedule. The work presented has been used to develop the schedule currently in use for the 2017 football season in Norway.

Friday, 8:30-10:00

■ FA-01

Friday, 8:30-10:00 - 307B

Analysis of complex and social networks

Stream: Telecommunications and network optimization
Invited session
Chair: Derya Dinler

1 - Evolutionary computing for high complexity networked systems: Study cases, issues and challenges
Cristian Duran-Faundez

We work on the optimization of high complexity networked systems. In this work we discuss three high complexity problems we have engaged in different projects: the first one is related to optimal interleaving of images for image communication, which can be used to enhance error robustness in unreliable networks, the second one is about optimal deployment of industrial sensor networks, which present special open optimization issues, and the third one is about optimal positioning and control for multi-robot colonies. For each problem we discuss last advances presented in the literature, and we discuss different ways we are currently studying to tackle them through evolutionary computing and other metaheuristics. Different mathematical models and implementations are discussed for each problem. Simulation results show promising interest on applying such a solutions, but they also show many open issues for operation research and other related areas.

2 - Network analysis of food security
Natalia Meshcheryakova, Sergey Shvydun

Food security which refers to the satisfaction of individuals' dietary needs and accessibility to food is a vital component of the national security of any country. There are many ways how to affect food security thus resulting in the change of living conditions of all individuals. In our work we study a food power of each country from the perspective of produce trade. The trade relations between countries are represented as a network, where vertices are countries or territories and edges are export/import flows. As flows of products between states are heterogeneous we cannot consider different types of products in a single network, this is why we consider 10 networks, where each network refers to one particular group of substitute goods (cereals, meat, etc.). To detect key participants affecting food security we calculate both classical centrality measures and short- and long-range interaction indices which consider individual attributes of countries (food production and consumption levels, etc.) and complex interactions between them. The analysis is based on annual reports of export and import data provided by the World Bank. The influence of countries through each homogeneous group of products was aggregated into a single food power index. We also studied how the influence of countries is changed over the years.

3 - Faster computation of successive bounds on the group betweenness centrality
Derya Dinler, Mustafa Kemal Tural

Numerous measures have been introduced in the literature for the identification of central nodes in a graph, e.g., group degree centrality, group closeness centrality, and group betweenness centrality (GBC). The GBC of a group of vertices measures the influence the group has on communications between every pair of vertices in the network assuming that information flows through the shortest paths. Given a group size, the problem of finding group of vertices with the highest GBC is a combinatorial problem. We propose a method that computes bounds on the GBC. Once certain quantities related to the network are computed in the preprocessing step taking time proportional to the cube of the number of vertices in the network, our method can compute bounds on the GBC of any number of groups of vertices successively, for each group requiring a running time proportional to the square of its size. Our method is an improvement of a method from the literature which has to be restarted for each group making it less efficient for the computation of the GBC of groups successively. In addition, the bounds used in our method are stronger and/or faster to compute in general. Our experiments on real-life social networks show that in the search for a group of a certain size with the highest GBC value, our method reduces the number of candidate groups substantially and in some cases gives the optimal group without exactly computing the GBC values which is computationally more demanding.

■ FA-02

Friday, 8:30-10:00 - 308B

Queueing systems

Stream: CORS SIG on queueing theory
Invited session
Chair: Steve Drekic

1 - Achieving service-level differentiation in a time-varying queue network
Xu Sun
We study the problem of delay-based service differentiation in a multi-class multi-server queueing system with time-varying arrival rates. Previous studies have succeeded in achieving service-level differentiation using fixed-queue-ratio (FQR) controls given stationary arrivals of each job class. We show by heavy-traffic analysis that with time-varying arrival rates, a naive application of the FQR control may fail to achieve desired differentiated service. In order to achieve delay-based service differentiation over multiple job classes, we propose an alternative family of controls that exploit the head-of-line delay information. This new family, which we refer to as head-of-line-delay-ratio (HLDR) control, extends the so-called accumulating priority rule in the literature and achieves desired differentiated service in an appropriate many-server heavy-traffic limiting regime. Our analysis has two interesting implications: (i) a fixed queue ratio (QR) and fixed HLDR can not be maintained at the same time in heavy traffic in the presence of time-varying arrival rates; (ii) for each HLDR control, there exits QR-type control such that these two controls are asymptotically equivalent.

2 - Equilibrium customer strategies in an M/M/1 vacation queue with Bernoulli schedule
Qingqing Ma, Yiqiang Zhao
We deal with the strategic joining behavior of customers in a single-server Markovian working vacation queueing system with vacation interruptions under the Bernoulli schedule. Based on a linear reward-cost structure, two cases are analyzed: in the observable case where the arriving customers have the information about the queue length and the server state, we obtain the equilibrium joining threshold of customers; in the unobservable case where the arriving customers only have the information about the server state but not the queue length, using the matrix analytic method, we obtain the stationary distribution for the system and the equilibrium joining probability of customers. The impact of the information level as well as system parameters on the equilibrium behavior is illustrated via numerical examples.

3 - A short note on the bulk-arrival multi-server queues involving heavy-tailed distributions
James Kim, Mohan Chaudhry
We demonstrate that the standard-root finding method can be applied to solve the bulk-arrival multi-server queues involving a general arrival pattern that follows heavy-tailed distributions. In the past, the standard-root finding method was believed to be ineffective due to the probabilistic properties of heavy-tailed distributions. Through the standard-root finding method, we show that not only can a single root (single-arrival) problem be solved, but multiple roots (bulk-arrival) can be found in a very efficient manner. Several numerical examples are provided to confirm this.

4 - A 2-class maintenance model with a finite population and competing exponential failure rates
Kevin Granville, Steve Drekic

We investigate a maintenance system interpreted as a single-server polling model. Within the model, we assume two classifications (or groupings) for types of failure that a machine may experience. There are C total machines in the system, which at any point in time are either working, in service, or waiting to be served in one of two queues. Working machines are subject to independent and identically distributed exponential failure rates. Machines are returned to working condition after eventually receiving service according to the class of their failure. Service and switch-in time distributions for each class are assumed to be phase-type. Multiple service disciplines are examined, including preemptive priority, non-preemptive priority, and exhaustive. We model the system as a level-dependent quasi-birth-and-death process, and use matrix analytic techniques to find the steady-state joint queue length distribution as well as the sojourn time distribution of a broken machine. We present numerical examples to investigate the dependency of the expected number of working machines on factors such as the service discipline, the total number of machines, and the probability of a non-zero switch-in time.

■ FA-03

Friday, 8:30-10:00 - 200AB

Keynote speaker: Sophie D'Amours

Stream: Keynote sessions
Keynote session
Chair: Richard Hartl

1 - Value chain modelling and optimisation in the forest sector
Sophie D'Amours

This tutorial will address the challenges of modelling and optimizing complex value chains systems in the forest sector. At the root of these systems, a chain of interdependent stakeholders collaborating and synchronizing their planning and operations to deliver social, environmental and economic values to customers, shareholders and the society as a whole. The complexity of the value chains in the forest sector resigns in conciliating time and space scales within the hierarchical planning framework as well as grasping the value of efficient collaboration between forest owners, industry and customers and the combinatorial effects of divergent manufacturing processes. Emerging paradigms to support long term forest planning will be discussed as well as hi-tech decision theaters to support collaborative decision makings process with multiple criteria, multiple stakeholders and complex system to analysis.

■ FA-04

Friday, 8:30-10:00 - 202

New trends in healthcare supply chains

Stream: Scheduling in job shops, flow shops, and healthcare
Invited session
Chair: *Vahid Kayvanfar*
Chair: Luciana Buriol

1 - Access to medicines supply chain design: A stakeholder framework
Nico Vandaele, Catherine Decouttere, Stef Lemmens, Mauro Bernuzzi, Amir Reichman, Sherif Hassane

The initial goal of any health care system is not only to address the medical needs of individuals and populations but also involves other factors affecting the general well-being of individuals and societies. The three main goals of a health care system, as stipulated by the World Health Organization (WHO) are: health improvement, responsiveness and fairness in financial contribution. Equally, in an end-to-end vaccine supply chain design context, these goals constitute the underlying ground for the multi-criteria evaluation of the way a vaccine supply chain is designed: the Access to Medicines (ATM) dimension needs to co-exist with the economic and technological ambitions. This boils down to the observation that a good supply chain design will make the best feasible combination of these multi-criteria evaluation metrics in order to reach as much as possible the aspirations of all stakeholders involved. We expose a data-driven supply chain design approach in five steps: (1) Stakeholder analysis and system definition, (2) Key performance indicators derivation and design requirements, (3) System design/modelling and scenario generation, (4) Scenario ranking and (5) Final scenario implementation.

2 - Evaluating flexible task and personnel scheduling in the home care sector
Federico Mosquera, Pieter Smet, Greet Vanden Berghe

Increasing demand for home care services has resulted in the need for new decision support models capable of optimizing the limited available resources. The home care scheduling problem concerns the assignment, scheduling and routing of caregivers so as to satisfy client demands. Despite the problem receiving increased attention in recent years, solving the problem remains a challenge given the various complex aspects that require consideration. The present study proposes a rich model for home care scheduling which takes into account current practices within three collaborating home care organizations. Specifically, emphasis is placed on accommodating the complexity of flexibility in scheduling both tasks and caregivers. For tasks, flexible duration and frequency are considered, while caregivers are employed under flexible contracts which allow for flextime. Data obtained from the three organizations is employed to demonstrate the model's impact. Computational results will be presented at the conference.

3 - A fix-and-optimize matheuristic for the nurse rostering problem
Luciana Buriol, Toni Wickert, Carlo Sartori

The Nurse Rostering Problem (NRP) aims to generate schedules to nurses according to certain restrictions. Constraints could be related to work laws, hospital interests, improvements on the patient care, nurse's availability, among others. The multi-stage and static variants of the problem were considered, i.e., the problem is solved week-by-week, or solved as a whole problem, respectively. In this work, we present an integer programming mathematical model for the problem, as well as a Fix-and-Optimize matheuristic for solving the NRP. The proposed algorithm, uses four different decompositions - week, nurse, day, and shift - in order to solve the problem. The method was applied on the multi-stage and static variants of the problem. The results were compared with the best known solutions (BKS) obtained by the winners of the Second International Nurse Rostering Competition (INRC-II). Also, an analysis was performed to find out which constraints turned the problem difficult to be solved by a standalone solver (CPLEX). The experimental results show that the proposed algorithm generates good solutions. In comparison with the results presented by the winners of the INRC-II, which run a multi-stage variant of the problem, our results on average are not as good as the winner method. However, our method generates feasible solutions for all instances in less than 15 seconds. When comparing both variants of the problem, in average, the static method generates better results.

■ FA-05

Friday, 8:30-10:00 - 203

Regularity of equilibria

Stream: Mathematical economics
Invited session
Chair: Julio Dávila

1 - Regularity of a general equilibrium in a model with infinite past and future
Anna Rubinchik

We develop easy-to-verify conditions assuring that comparative statics in a general equilibrium model where time is a real line is feasible, i.e., the implicit function theorem is applicable. Consider an equilibrium equation, U(k,E)=k of a model where an equilibrium variable (k) is a continuous bounded function of time, real line, and the policy parameter (E) is a locally integrable function of time. The key conditions are time invariance of the equilibrium map U and the requirement that the Fourier transform of the derivative of the map U with respect to the equilibrium variable k does not return unity. Further, in a general constant-returns-to-scale production and homogeneous life-time-utility overlapping generations model we show that the first condition is satisfied at a balanced growth equilibrium and the second condition is satisfied for "almost all" policies that give rise to such equilibria.

2 - Generic determinacy for overlapping-generations models
Jonathan Burke

We prove a type of generic determinacy for overlapping-generations models with a continuum of differentiated commodities in continuous time. That includes finitely many commodities in discrete time as an exceptional special case. Hence, for many of the leading examples of indeterminacy in the literature there exists a generic perturbation of the underlying model that ensures determinacy. Such findings contrast the common conclusion that indeterminacy in those examples is robust.

3 - Optimal human capital bequeathing
Julio Dávila

When parents endow their offspring with human capital and the effectiveness with which they do so depends on their own, the decentralized allocation of resources through markets cannot deliver, under laissez-faire, the benevolent planner's outcome maximizing the representative agent's welfare. Specifically, the market level of human capital is too low. The planner's allocation can nonetheless be decentralised through the market subsidizing labor income at the expense of a lump-sum tax on saving returns.

■ FA-06

Friday, 8:30-10:00 - 204A

Soft OR and problem structuring methods

Stream: Problem structuring interventions
Invited session
Chair: Joaquim Heck

1 - Conceptualizing career success in Nepal: Gender differences
Sunity Shrestha Hada, Gyan Bahadur Tamang, Santosh Raj Poudyal

The purpose of this paper is to explore the gender differences in conceptualizing career success in Nepalese context. This paper has drawn 13 different indicators of career success from review of literature and items representing each of these indicators used in survey conducted in civil service and banking sectors. Factor analysis was used to identify the indicators defining career success from gender perspective.The paper found gender differences in conceptualizing career success.

2 - Workers' remittances and economic growth: Evidences from Nepal
Gyan Mani Adhikari

Aim of the talk is to examine the empirical relationship between Workers' Remittances inflow and economic growth in Nepal based on OLS models. The study found that there is a non linear relationship between workers' remittances inflow and economic growth in Nepal.

3 - Re-examining the 'value' of a PSM engagement
Patrick Tully, Mike Yearworth, Leroy White

Addressing the problem of selling the value (considered here mostly as mutual financial benefit) of a Problem Structuring Method (PSM) engagement to a client in a consulting relationship is fraught with difficulty. A consultant attempting to sell PSM engagements will struggle to articulate the value to clients in terms that are commercially meaningful prior to agreement for their use. Thus, in order to win a PSM engagement the consultant must first resolve this puzzle. We explore this question by reviewing how the value of PSMs has been assessed previously and setting out a theoretical basis to address the question. Our theoretical development leads to the recognition that the process of selling a PSM engagement is bound to the interposition of the processes of problematization and interessement and the issue of trust. We shift attention to the pre-contractual phase of the relationship between a consultant and client and discuss implications of this paradox for Soft OR practice.

4 - Problem structuring methods: Mapping the literature, 1954-1989
Joaquim Heck, Ion Georgiou

A bibliographic atlas of the literature of four main problem structuring methods (PSMs) is presented, ranging from historical precedents in the 1950s to the first edition of Rational Analysis for a Problematic World in 1989 (RAPW-1989). The constitutive maps, with complementary descriptive statistics, offer multiple views of the literature, ranging from high-level panoramas to detailed tracings of the development of the literature through time. Overall, the atlas is divided into three main sections respectively focusing on coverage, sources, and media, each of which allows synchronic and diachronic views. Comparisons between the contents of the sources represented in the maps, and the manner in which PSMs were introduced in RAPW-1989, reveal opportunities for enhancing understanding of PSMs. For example, the atlas stimulates reflection on the unity of PSMs; on the relationship between PSMs and the perceived crisis that engulfed OR in the 1980s; and, on undervalued or underexposed historical precedents in the literature. Furthermore, the historical, synthesized reading mapped by the atlas provides an opportunity to revise and enhance the nature of the alternative OR paradigm which underpins PSMs.

■ FA-07

Friday, 8:30-10:00 - 204B

Electric vehicle routing

Stream: Vehicle routing
Invited session
Chair: David Cortes

1 - How to employ mobile electric platforms for drone-based parcel deliveries
Hagen Salewski, Dominik Goeke

Quicker deliveries, less inner-city traffic, and independence from road networks are the advantages of drone-based deliveries. Electric vehicles offer reduced noise and local greenhouse gas emissions. Integrating both technologies increases their individual potential to improve the quality of life in mega cities as well as in rural areas. The main obstacles are the limitation of the drones' range and available energy. In 2016, Amazon introduced one possible remedy: Drone platforms (airships) positioned above a delivery area. They dispatch drones which exploit the force of gravity to descend to their target destination and continue -without payload and therefore lower energy consumption - to ground-based collection points. Daimler recently presented prototypes of delivery vans serving as road-based drone platforms. In urban centers, smaller autonomous transport vehicles are used to drive into pedestrian areas. Another prototype operates airborne drones for faster deliveries in rural regions. Only a few articles about delivery with drones exist. However, they do not consider multiple platforms or several drones. We propose a general model for the routing of electric platforms, applicable to all three use cases. It considers a fleet of platforms and integrates drone scheduling. Each platform's range is restricted, and it shares its energy with the drones. The model minimizes the energy consumption of the entire system. We solve example instances using heuristic methods.

2 - Route design for mixed fleet of hydrogen and conventional vehicles
Md Anisul Islam, Tarek ElMekkawy, Yuvraj Gajpal

In this study, a new variant of GVRP named as hydrogen and mixed fleet based green vehicle routing problem with recharging station (H-MFGVRPRS) is considered. The study is motivated from the global concerns about environmental sustainability challenges and subsequent imposed CO2 limit for the businesses. Associated with real-life scenarios, a pragmatic energy consumption method and its CO2 emission model of the vehicles is considered as non-linear function of travel distance. The models incorporate the realistic variation of vehicle speed and cargo load on the calculation of CO2 emission. Overall, it is a new GVRP of a mixed fleet and heterogeneous vehicles consist of fuel cell hydrogen vehicle and conventional internal combustion vehicle with alternative fuel stations (AFSs). For the problem, new datasets are generated and utilized for computation analysis in this study. The problem is mathematically formulated as mixed integer programming (MIP) and a meta-heuristic algorithm is designed to solve the problem.

3 - Formulation of the traveling salesman problem with multiple drones and its solution
Youta Ueda, Hiroyuki Ebara

In resent years, Unmanned Aerial Vehicles(UAV) developed for military use are being used by the private sector. Also, UAV is sometimes called a drone. Amazone.com plans to deliver parcels using drone "Amazone Prime Air". This plan uses drones to deliver parcels from distribution centers directly to customers. However, this method can only deliver parcels to customers near the distribution centers. So, the method has been proposed, in which a truck carries a drone near the customer and the drone delivers a parcel to the customer. By coordinating trucks and drones well, they can shorten the delivery times. However, the method considers only when there is one drone. There is no research on modeling delivery using multiple drones. In practice, the truck can carry multiple drones and can be delivered to multiple customers at the same time. This paper formulates the traveling salesman problem with multiple drones as mixed integer linear programming and also calculate using Ant Colony Optimization. By using multiple drones, the delivery can be done more efficiently than that using single drone. As a result of acually solving the problem using a solver, we are able to deliver parcels in a shorter times comparing with the case of delivering by truck only. It is also found that the more drones we use, the shorter the delivery time becomes.

4 - Electric vehicle routing problem with satellite customers and time windows
David Cortes, Caroline Prodhon, H. Murat Afsar

The research in green logistics gives importance to Electric Vehicles (EVs) due to its benefits: no local greenhouse emission, less noise and governmental subsidies. As consequence, transportation of goods using EVs is getting more importance as an alternative for companies to manage the new laws, which regulate the greenhouse gas emissions in transportation and logistics operations. The e-VRPTW is a variant of the vehicle routing problem where the fleet is composed by EVs, customers have time windows, the vehicles have an autonomy and Recharging Stations (RS) are able to recharge the vehicles during the operation. In this talk, a variant of the e-VRP is studied. In this case, it allows visiting a customer by walking while an electric vehicle is recharged at a RS. A MIP model and a heuristic method are presented and compared with public benchmark instances .Preliminary results show that the total time at the RSs could be reduce up to 7% and the total distance performed by the EVs could be reduce up to 8%. This variant is pertinent for small-package shipping or maintenance services industries because of the large recharging times of the EVs.

■ FA-08

Friday, 8:30-10:00 - 205A

Decision analysis applications

Stream: Decision analysis
Invited session
Chair: Eeva Vilkkumaa

1 - Multi-period procurement decisions under piecewise-linear shortage costs and fixed capacity commitments: Application to gas procurement
Ville Sillanpää, Juuso Liesiö, Anssi Käki

We study optimal procurement in a case where the buyer must match supply against uncertain demand using a combination of low-cost order-in-advance procurement contracts and a high-cost real-time balancing mechanism. The procurement contracts have a hierarchical structure in which the commitment to procure a fixed quantity for multiple periods has a lower unit-price than period-specific commitments. Moreover, the balancing mechanism implies a salvage value for unused supply and piecewise-linear shortage costs: small shortages (relative to the total quantity procured) are balanced with a lower unit cost than larger shortages. Minimizing procurement costs results in a stochastic non-linear multivariate optimization problem, which can be interpreted as a generalization of the classic newsvendor model. We derive the optimality conditions for this problem and show how they can be utilized to obtain a cost minimizing procurement strategy by solving a series of single variable equations. We also report results from using the model to support procurement decision making of a pulp & paper company that procures natural gas worth tens of millions of euros annually.

2 - Advanced medical decision support using fuzzy cognitive maps: A review of recent applications
Afshin Jamshidi, Angel Ruiz, Daoud Ait-kadi

Fuzzy cognitive maps (FCMs) have been widely applied in the last decade in several scientific areas such as engineering and control, pattern recognition, energy industry, business and management, healthcare, political and social sciences, and data prediction and forecasting. This paper reviews the recent applications of FCMs as an advanced decision support tool in healthcare such as medical diagnosis, assessment of breast cancer risk, prediction of prostate cancer, prediction of infectious diseases, etc. In addition, some potential applications of FCMs in healthcare as future research are proposed at the end of this paper which could be a starting point to develop tools and policies for improving current healthcare systems.

3 - A decision-analytic approach for the optimal design of population-wide diagnostic testing strategies
Eeva Vilkkumaa, Yrjänä Hynninen, Ahti Salo

Diagnostic tests increase the likelihood of a correct diagnosis but also consume resources which could otherwise be allocated to treatment. Therefore, it is important to allocate limited resources between testing and treating such that the benefits resulting from better-informed treatment decisions can be expected to offset the negative impact of decreasing the amount of resources for treatment. The identification of optimal testing and treatment strategies requires optimizing across the entire population of patients. It is necessary to define how to divide the population into different risk segments, how to allocate resources to each risk segment, and which tests and treatments to carry out to each segment within these resources. If there are multiple tests, treatments, and testing stages, solving this optimization problem becomes computationally challenging. We develop a model for the identification of testing and treatment strategies that maximize the expected health outcome for the population subject to limited resources. Our model helps understand how changes in the level of total resources affect (i) the optimal segmentation, (ii) the choices of tests and treatments for each segment, and (iii) the health outcome of the population. Such results can be used to support cost-effectiveness analyses of adopting new testing or treatment technologies, and to provide information for decisions about the appropriate level of investment into the care of a particular disease.

■ FA-10

Friday, 8:30-10:00 - 205C

Competitive location

Stream: Location
Invited session
Chair: Blas Pelegrin

1 - An MINLP model for locating a competitive facility in the plane when attractiveness adjustment and/or closing of the existing chain-owned facilities is allowed
Jose Fernandez, Boglárka G.-Tóth, Juana Lopez Redondo, Pilar M. Ortigosa

When locating a new facility in a competitive environment, both the location and the quality of the facility need to be determined jointly and carefully in order to maximize the profit obtained by the locating chain. However, when a chain has to decide how to invest in a given geographical region, it may also invest part of its budget in modifying the quality of other existing chain-owned centers (in case they exist) up or down, or even in closing some of those centers in order to allocate the budget devoted to those facilities to other chain-owned facilities or to the new one (in case the chain finally decides to open it). In this talk we introduce a continuous facility location and design model model to accommodate all those possibilities. The demand is supposed to be fixed and concentrated in a finite number of demand points. The patronizing behavior of customers is assumed to be probabilistic (Huff-like model), with an attraction function determined as quality of the facility divided by a function of the distance between the facility and the demand point. Some constraints are also included in the model. Existing solvers for MINLP problems (namely, BARON, COUENNE, Knitro, LaGO, Local Solver, SCIP) are applied to the new model. Some computational results are reported. Due to their limited success, a heuristic procedure is also proposed.

2 - A discrete competitive location problem with additional constraints
Pascual Fernandez, Blas Pelegrin, Algirdas Lančinskas, Julius Žilinskas

The location of facilities is a strategic decision for a firm that competes with other firms to provide goods or service to the customers in a given geographical area. An entering firm is aimed at determination of the optimal locations for the new facilities with respect to maximization of the market share or profit, taking only into account the patronizing behavior of customers. Traditionally it is assumed that the customers choose the nearest facility to be served, but, in addition to the distance, the customer can take into account some characteristics of the facilities for its choice. All these characteristics are considered as only one, and it is called the quality of the facility. The most common customer choice rules are the proportional and binary rules. In this work, we will study a more general model on discrete space in two ways, first considering other different rule of customers' choice, the Partially Binary, and second introducing additional constraints to the basic model, constraints in which each new facility has to capture a minimum demand. Due to the difficulty of these problems, heuristic algorithms are proposed, which could be used also to solve other discrete competitive location problems. The performance of the proposed heuristic algorithms will be justified by comparing its solutions with the optimal solutions given by a standard optimization software, since it is shown that this problem can be formulated as an Integer Linear Programming problem.

3 - Ranking based heuristic algorithm for discrete competitive facility location problems
Julius Žilinskas, Algirdas Lančinskas, Blas Pelegrin, Pascual Fernandez

The location of facilities is a strategic decision for a firm that competes with other firms to provide goods or services to the customers in a given geographical area. There are a lot of location models and their solution procedures have been proposed to cope with these problems which vary depending on their properties. In particular, we consider discrete competitive facility location problems for an entering firm which competes with other firms already in a market where customers are spatially separated. In these problems, a given number of facility locations must be selected among a finite set of candidate locations. We present a heuristic algorithm which is specially adopted to solve discrete competitive facility location problems, and is based on ranking of candidate locations taking into account the success of their inclusion to form a candidate solution. The performance of the proposed algorithm has been evaluated and compared with performance of specially adopted Genetic Algorithm by solving various instances of competitive facility location problems for an entering firm using a set of real geographical and population data. Results of the experimental investigation showed that the proposed algorithm is able to determine optimal locations for a set of new facilities and notably outperforms Genetic Algorithm which is assumed to be suitable for such kind of optimization problems.

4 - The follower location choice under quantity competition
Blas Pelegrin, Pascual Fernandez, María D. García

We study the location choice problem for an entering firm that will compete with other firms that are already stablished and offer the same type of product. Customers are physically separated and grouped in markets with heterogeneous demand at different locations. Competition is performed on the quantities delivered to the markets. Price in each market is determined by the total quantity available at the market via the Cournot mechanism. We develop a Binary Linear Programming model to determine the optimal locations for the entering firm with the aim of profit maximization. An illustrative example with data from the Spanish municipalities is presented which is solved in a variety of scenarios.

■ FA-11

Friday, 8:30-10:00 - 206A

Issues in supply chain management

Stream: Supply chain management
Invited session
Chair: Mario Dobrovnik

1 - Relevant measure for quantifying supply chain complexity

Mozart Menezes, Kyle Hyndman

In this work we consider information as the main input for managerial decision-making processes. Using the amount of information contained in the product mix as a proxy for complexity - the difficulty to properly manage supply chain operations due to "excessive" amount of information - we take advantage of Shannon's measure of information to address the following question: Is there a measure for supply chain complexity that results directly from the business strategy? Can we show the relevance of such measure? We present a measure for complexity and support the measure's relevance through empirical evidence demonstrating the correlation between the measure and supply chain an d firm performance. There are several findings after measuring complexity. The measure sheds light on how complexity changes when several transformations are applied to them supply chain design including merger & acquisitions, postponement, management re-organizations, market expansion, supply chain consolidation, change in product mix, among others.

2 - Performance analysis of the Moroccan forest supply chain

Zainab Belalia, Fouzia Ghaiti

In supply chain management, academic researchers have been recently interested in the wood value chain or forest supply chain. In Morocco, a country with a modest forest heritage, the management of forest resources is a major challenge. Until today, the distribution of the working area is realized independently of the final demand, and over a relatively long period, since the lifecycle of a tree is between 100 to 400 years. In addition to economic constraints, there are social and ecological constraints specific to the country, which makes Moroccan forests mainly forests of protection. Morocco then turns to imports in order to satisfy the lumber demand, and sometimes even fuel wood demand. The only wood intended for production is cork; this is the main reason why our study will focus on this product. The paper discuss the specificities of cork supply chain in Morocco and analyze its performance. Therefore, the aim of the present paper is first to highlight the different issues related to the forest supply chain in this country. Moreover, we investigate the different causes of the discrepancies observed between supply and demand in the cork supply chain. Finally Some research perspectives are suggested.

3 - On the acceptance of gain sharing methods in supply chain collaboration

Verena Jung, Alexander Grigoriev, Marianne Peeters, Tjark Vredeveld

Due to a constantly growing competition among organizations and higher customer expectations, in the last decades companies started to realize the need for supply chain collaboration (SCC). However, next to advantages, SCCs bring along challenges. In this paper we focus on the challenge of dividing the coalition gain among the parties. To increase the willingness of the parties to join further SCCs, it is important that every party is satisfied with and accepts the assigned amount of the coalition gain. For a long time, the predominate assumption in economics was that humans are rational thinking agents. However, humans have a bounded rationality and their decisions are influenced by cognitive biases. To ensure practical validity, it is necessary to incorporate behavioral research in studies. Therefore, in this paper the influence of behavioral decision-making aspects on the acceptance of gain sharing methods is investigated. It is shown, that behavioral decision-making aspects like the availability of information and cognitive biases have a significant influence on the acceptance of gain sharing methods. The study provides novel insights in the understanding of the acceptance of gain sharing methods through the integration of behavioral decision-making literature. Practical implications of the results include that all relevant information has to be provided in order to increase the acceptance of gain sharing methods.

4 - Supply chain process re-use: An analysis of concepts, methods, and techniques

Mario Dobrovnik, Sebastian Kummer

Supply chain executives strive to achieve business process and operational excellence. However, designing and managing global supply chain processes is a challenging and complex task. By using information models, an attempt is made to create manageable artifacts with which their inherent complexity becomes controllable (Thomas, 2005). This is why many organizations commit significant resources to process modeling and to creating and maintaining process model collections. Yet, many of these models or even entire collections fall into disuse, which means that investments in process modeling are at risk of being lost (Nolte et al., 2016). In order to use resources as efficiently as possible, instead of developing new solutions each time, organizations can use existing processes and known business process practices as a point of reference for the development of new, problem-specific models. However, in order to re-use existing concepts, organizations as well as their supply chain partners must be able to identify internally and externally available information models and have to be capable and willing to assimilate, transform, and apply this knowledge within their supply chains. This study aims at analyzing concepts, methods, and techniques facilitating re-use of process based models in logistics and supply chain management. It also identifies technical and organizational success factors and provides guidelines for reference process modelers and reusing entities.

■ FA-12

Friday, 8:30-10:00 - 206B

Sports analytics

Stream: Sports analytics
Invited session
Chair: Donald Hearn

1 - Performance of PGA TOUR golfers surrounding extreme golf-related outcomes

Richard Rendleman

In this study, we examine the hole-by-hole performance of PGA TOUR players before and after experiencing extremely favorable and unfavorable golf-related events. Favorable events include: (1) type-1 eagles (eagle on a par-3, long par-4, or double eagle on par-5), (2) type-2 eagles (eagle on a short par-4 or any par-5), (3) two birdies or better in a row, and (4) three birdies or better in a row. Unfavorable events include (1) a single double bogey, (2) a single triple bogey, (3) a single quadruple bogey or worse, and (4) two double bogeys or worse in a row. We believe that the four favorable events are largely a reflection of good luck, but less luck as we move from favorable event 1 to favorable event 4. On the other hand, the four unfavorable events are less likely to reflect bad luck. Our preliminary results indicate that after adjusting for differences in player skill, when players experience a very favorable golf-related event (by hole or holes), very little, favorable or unfavorable, in a golf-related sense tends to have been going on before or after the event. If anything, there is a slight tendency for post-event performance to be better than normal in connection with favorable events that are less luck-related. By contrast, players who experience a very unfavorable golf-related event (by hole or holes) tend to have been playing relatively poorly both before and after.

2 - Algorithms and software for the golf director problem
Giacomo Benincasa, Konstantin Pavlikov, Donald Hearn

The golf director problem introduced in Pavlikov et al. (2014) aims to find an allocation of golf players into fair teams for certain golf club competitions. As an approximation, an optimization model was formulated where players of various handicaps are assumed to play a one-hole match and determine the result of a team based on the best individual score. This model used the score distributions by handicap from Siegbahn and Hearn (2010). This study uses the same distributions, but considers the expanded version of the golf director problem where the game is played over 18 holes and the team score is based on the scores (hole by hole) of multiple players on the team. One of the main challenges of the 18-hole game is the fact that (gross) scores of different players are adjusted on certain holes according to player handicap and hole difficulty. Thus, all holes are not the same with respect to scoring. However, one-hole games serve as a basis to obtain a set of good team allocation candidates for the real 18-hole game. We present an efficient simulation and optimization based procedure, available on the website http://www.fairgolfteams.com, which finds a near-optimal fair teams allocation. Computational results are presented using real data sets.

3 - Predicting the outcomes of professional darts tournaments
Thomas Kirschstein, Steffen Liebscher

In recent years darts has become increasingly popular. Along with popularity, professionalization took place e.g. by founding the Professional Darts Corporation (PDC). As a consequence, regular leagues and tournaments are organized such as the Premier League Darts and annual World Championship. Like in most professional sports, along with professionalization, data analytics becomes more and more important as a lot of money is at stake for multiple stakeholder groups, like fans, bookmakers, players, and organizers. In this research project we have gathered and analyzed data from more than 800 professional darts matches in 2016 in order to predict the outcome of professional darts matches. In this talk, we present prediction models for professional darts matches. As a corner stone, prediction models for the winner of a 1-set match are estimated. Therefore, various variables are analyzed including typical player statistics as well as match data as predictors. For the test sample, we could predict winners correctly in about 70 - 80 % of all cases. To analyze the outcome of multi-set matches, as commonly played at major tournaments, the prediction model is embedded into a Poisson binomial process. After formally introducing the negative Poisson binomial distribution, we show that the probabilities of all potential outcomes of complete tournaments can be calculated. We illustrate the procedure by estimating outcome probabilities for the latest world darts championship.

■ FA-13

Friday, 8:30-10:00 - 207

Applications of conic optimization

Stream: Copositive and conic optimization
Invited session
Chair: *Miguel Anjos*
Chair: *Tamás Terlaky*

1 - New Conic Relaxation for AC Optimal Power Flow
Christian Bingane, Miguel Anjos, Sébastien Le Digabel

The classical Alternating Current Optimal Power Flow problem is highly non-convex and generally hard to solve. Recently, convex relaxations, in particular, semidefinite, second-order cone, convex quadratic, and linear relaxations have attracted significant interest. The semidefinite relaxation is the strongest among them and is exact for many cases. However, the computational efficiency for solving large-scale semidefinite optimization is lower than for second-order cone optimization. We propose a conic relaxation which is derived by a combination of semidefinite optimization and reformulation-linearization technique, commonly known as RLT. The proposed relaxation is stronger than the second-order cone relaxation and nearly as tight as the semidefinite relaxation.

2 - Computational study of valid inequalities for the maximum k-cut problem
Vilmar Rodrigues de Sousa, Miguel Anjos, Sébastien Le Digabel

We consider the maximum k-cut problem that consists in partitioning the vertex set of a graph into k subsets such that the sum of the weights of edges joining vertices in different subsets is maximized. We focus on strengthening conic relaxations of max-k-cut by adding facet-defining inequalities, specifically clique, general clique, wheel and bicycle wheel inequalities. We also study valid linear inequalities based on a reformulation of the semidefiniteness constraint. Our computational results suggest that these inequalities considerably improve the performance of the relaxations.

3 - Pathological cases in deriving disjunctive conic cuts for mixed integer second order cone optimization problems
Tamás Terlaky, Mohammad Shahabsafa, Julio Góez

The development of Disjunctive Conic Cuts (DCCs) for Mixed Integer Second Order Cone Optimization (MISOCO) problems has recently gained significant interest in the optimization community. Identification of pathological cases when DCCs are not useful, saves computational time, and avoids complication arising from the presence of redundant conic constraints. In this study, we explore cases where the DCC methodology does not derive a DCC which cuts off any part of the feasible region.

■ FA-14

Friday, 8:30-10:00 - 305

Combinatorial optimization 2

Stream: Combinatorial optimisation
Invited session
Chair: *Vinícius Motta*

1 - An optimization model for the safe set problem on graphs
Ana Flavia Macambira, Pedro Henrique González, Luidi Simonetti

Building spaces are increasingly more expensive, and thus, must be used in an intelligent way. One of the applications of the Safe Set problem on graphs deals with placing temporary refuges in a given topology of a building. These temporary refuges should be ready to be used and/or accessed by people in every adjacent business spaces, which leads to capacity issues. There is no need that refuge spaces are adjacent spaces, although they can be. Once the topology of the building have been given, the problem is where to place the temporary refuges in a way that business places are maximized. In literature, this problem is named Safe Set Problem on Graphs and it is proved to be NP-Complete. In order to mitigate the capacity issue, in this work there is an assumption that every temporary refuge has capacity to receive people of every adjacent business spaces. A mathematical formulation for the problem is proposed considering any given graph and a heuristic is presented in order to solve it.

2 - The minimum covering problem of three dimensional bodies using different radius spheres
Marilis Bahr Karam Venceslau, Helder Venceslau, Nelson Maculan

The minimum covering problem of three dimensional bodies using different radius spheres will be presented, intending its use on the treatment planning of Gamma Knife radiosurgery. Gamma Knife unit delivers suitable doses of ionizing radiation, called shots, to the target tumor region. These shots can be modeled as spheres of different sizes. Multiple shots can be used to cover the entire tumor, while avoiding an excessive dose to the surrounding healthy tissue. The presented approach deals only with the geometric covering point of view: given a set of spheres and a body, the objective is to fully cover the body using the smallest possible number of spheres, not considering the dosage issue. In order to solve this mathematical programming problem, we consider an approach based on the application of penalty and stochastic heuristic search techniques.

3 - Advances in solving graph coloring problems with distance constraints
Rosiane deFreitas, Bruno Cardoso Dias, Nelson Maculan, Jayme Szwarcfiter, Philippe Michelon, Javier Marenco

We show the advances in solving graph coloring problems with distance constraints, where a key application is in the planning of resource allocation in telecommunications. We present some theoretical graph coloring models, where the coloring must respect certain geographic and technological distance constraints. A seminal problem was the generalized coloring problem (GCP) or just T-coloring, whose adjacency constraint involves a subset of forbidden values to be respected. When the absolute difference between colors assigned to each vertex must be greater than or equal a certain value, we have the bandwidth coloring problem (BCP) and channel (frequency) assignment problem (CAP or FAP). In our work we consider uniform and arbitrary distances, and some (in)equalities constraints, defining a set of vertex coloring problems with distance constraints, called distance graph coloring problems, modeling them as distance geometry problems. IP formulations and heuristics-exact methods are discussed in this work.

4 - Model for power grid optimal planning including renewable energies
Vinícius Motta, Nelson Maculan

The participation of renewable energies, such as solar and wind energy, in the energy mix has been increasing substantially in Brazil and in the world. In Brazil, it's predicted that in 2024 there will be 24 GW of installed generating capacity with wind plants and 7 GW with solar plants. However, in Brazil, most of the existing power grid optimal planning models don't consider the uncertainty on planning that originates because of the insertion of wind and solar plants in the power grid. Specifically, this uncertainty is originated in the wind speed and solar irradiation data. Also, in Brazil, these models don't consider wind and solar plants separately, instead, they consider these as non-simulated plants. Therefore, the objective of this work is to implement an optimization model that takes into account not only water inflow uncertainty, but also wind speed and solar irradiation uncertainty. It will also consider separately wind and solar plants. Not only that, but it also aims at analyzing the impact of wind and solar energy in the operation and planning of the Brazilian power grid.

■ FA-15
Friday, 8:30-10:00 - 307A

Managing risk in supply chains

Stream: Managing risk in supply chains
Invited session
Chair: *Iris Heckmann*
Chair: *Sha Zhu*

1 - Strategic design of robust and flexible supply chain networks
Matias Schuster, Jean-Sébastien Tancrez

Demand uncertainty has two main implications in the design of a supply chain: (i) in the short term, it forces companies to store safety stocks, and (ii) in the long term, it may affect the location of the retailers and the balance of the demand flows. We propose a robust optimization model for the location-inventory problem with demand uncertainty. We consider two stage supply chains, with distribution centers (DCs) and retailers. The model minimizes transportation, inventory, order, safety stock, lost sales and facility opening costs. Our robust model is based on a multi-scenario approach in which the possible future demands are described by discrete scenarios, each with a given probability of occurrence. We assume that the location and capacity of DCs is decided before knowing which scenario will occur, and once the demand is observed, tactical and operational decisions are made. These decisions include the allocation of flows, the transportation modes, the use of temporary DCs, the retailer's selection, the shipment sizes and the safety stock level. The resulting model is non-linear, and we reformulate it as a conic quadratic mixed-integer program, which can be solved using standard optimization software packages. To show the efficiency of the program, we conduct a large set of computational experiments and infer interesting managerial insights related to the design of robust and flexible supply chains, and study the impact of demand uncertainty.

2 - Critical product planning and spare parts inventory management for shutdown of a refinery
Sha Zhu, Willem van Jaarsveld, Rommert Dekker

A project plan of activities are carried out for a shutdown or an overhaul of a refinery. Given a set of activities and predecessors, spare parts might be needed for each activity. The shortage of spare parts for some activities, e.g. activities in the critical path, would influence the completion time of the project and each unit of time that exceeds the deadline may lead to a penalty which could be huge in practice. On the other hand, stocking a spare part leads to holding cost and the slack time associated with noncritical activities allow some positive lead time of spare parts for these activities. This study aims to make the most economic decision so that we can have a satisfied completion time and relatively low inventory cost. In order to solve this problem, we proposes an estimation of the probability that a certain type of spare parts might be needed in each activity depending on the condition of the refinery. Then we formulate the refinery shutdown inventory problem as a two-stage stochastic program and obtain the optimal order policy.

■ FA-16
Friday, 8:30-10:00 - 308A

Optimal control applications 2

Stream: Optimal control applications
Invited session
Chair: *Babatunde Giwa*

1 - Optimal control of tank levels with constrained chance of pipeline shutdown
Tianyuan Zhu, Zhankun Sun

In petroleum supply chain, planning and scheduling problems of a pipeline and the associated end-of-pipe tank farm have been extensively studied. However, when unexpected power failure or other malfunctions happens during a predetermined schedule, the unusual change of pipeline flow rate may lead to excessively high or low inventory level in tank farms, which will result in connecting pipeline shutdowns and network throughput missing. To address this problem, an optimization model is developed to study the optimal tank levels and associated pipeline flow rate adjustment policy with the objective of minimizing the missing throughput, while the chance of pipeline shutdown is bounded. The model is tested on a simplified real-world network owned by a Canadian pipeline company.

2 - A centralized reinforcement learning algorithm for the optimization of multiple HVAC systems in a shopping mall
Babatunde Giwa, Ji-Su Kim, Mustafa Shaikh, Chi-Guhn Lee, Simone Stancari

We consider the optimal control of multiple and connected Heating Ventilation and Air Conditioning (HVAC) systems in a shopping mall to provide shopper with pleasant condition at a minimum cost. Specifically, we optimally decide the temperature set-points of three connected HVAC systems in response to the condition of the shopping mall characterized by external and internal temperatures, humidity levels and estimated number of shoppers based on CO2 concentration level. The objective is to minimize the total energy consumption and the penalty proportional to the aggregate deviation of comfort level among shoppers currently present in the mall. We formulated the problem as a Markov Decision Process (MDP) model, and then develop a centralized Reinforcement Learning (RL) algorithm. Historical data from an Italian mall have been utilized to train the Q-matrices, which converge to their limits. Computational studies have been performed to shed light on the complex trade-off between the energy cost and the shopper's experiences given various weights. Also, studies is the impact of the weight on the variability of the energy cost vs. the deviation of the comfort level to help management set the weight strategically.

■ FA-17

Friday, 8:30-10:00 - 309A

Applications in call centers and aircraft arrivals scheduling

Stream: Nonlinear optimization with uncertainties
Invited session
Chair: Fabian Bastin

1 - Using K-means to improve two-stage chance-constrained staffing for multi-skill call center with arrival rate uncertainties
Wyean Chan, Thuy Anh Ta, Pierre L'Écuyer, Fabian Bastin

Multi-skill call centers are complex queueing systems whose performance measures (or quality of service) can, in general, only be estimated adequately by simulation. The current best staffing algorithms use simulation-based optimization, but their applicability in practice are sometimes impeded by time-consuming simulations. The challenge is even greater when solving a two-stage stochastic version of the problem with scenario generation approach. We propose a heuristic to optimize the two-stage staffing problem efficiently by considering only a subset of scenarios selected by the K-means algorithm. This heuristic can greatly reduce the computation time while only losing little on the quality of the solution.

2 - Scheduling aircraft landings in the presence of uncertainty
Ahmed Khassiba, Fabian Bastin, Marcel Mongeau, Sonia Cafieri, Bernard Gendron

Facing the world-wide steady growth of air traffic, air traffic controllers (ATCs) are more and more challenged to schedule optimally aircraft operations on runways and most importantly landings. The Aircraft Landing Problem (ALP) arises as one consisting in finding the best landing sequence with regard to (a) particular objective(s) and subject to a number of operational constraints. To help ATCs with this task, decision support tools (DSTs) have been designed since the early 90's. Nevertheless, the most wide-spread landing policy is still First Come First Served (FCFS), even though it has been proved sub-optimal in many deterministic problem statements. Moreover, ALP is a dynamic and stochastic problem by nature. Stochasticity is even more highlighted as DSTs tend to double increase their planning horizon in the near future. We propose a two-stage stochastic program to address the aircraft landing problem under uncertainty, where aircraft predicted arrival times at the near airport area, called TRACON, are assumed to follow known probability distributions. In the first stage, we seek to find an aircraft sequence as well as appropriate target arrival times at TRACON, where the former would minimize runway usage. In the second stage, once the actual arrival times at TRACON are revealed assuming unviolated aircraft sequence, we decide on target landing times that minimize ATCs' workload. We use the Julia programming language to model and solve realistic problem instances.

3 - On the sample average approximation of the two-stage chance-constrained staffing problem in call centers
Thuy Anh Ta, Wyean Chan, Pierre L'Écuyer, Fabian Bastin

We consider a chance-constrained two-stage stochastic staffing problem for multi-skill call centers with arrival rate uncertainty. The aim is to minimize the total cost of agents under some chance constraints, defined over the randomness of the service level in a given time period. We use the Monte Carlo method to generate M scenarios of arrival rates and we perform N simulation runs to get the estimates of probabilities that the service level is satisfied. We then obtain a sample average approximation (SAA) of the problem. We investigate the convergence of the optimal solution of the SAA to that of the original problem when the sample size increases and present numerical illustrations on the sample sizes M and N.

■ FA-19

Friday, 8:30-10:00 - 2102AB

Data-driven models in dynamic pricing

Stream: Data driven modeling in operations management
Invited session
Chair: Soheil Sibdari
Chair: *Roozbeh Yousefi*

1 - Infrastructure investment as a risk mitigation strategy in railroad transportation of hazardous materials
Ali Vaezi, Manish Verma

Railroad transportation of hazardous materials (hazmat) has grown significantly in recent years in Canada. We propose a risk mitigation strategy based on infrastructure investment, i.e., building new railway tracks in such a way that hazmat traffic is taken away from the riskiest locations across the rail network. Our risk analysis shows that these locations are mostly the same as major population centers. Such an alternative network for hazmat transport is expected to benefit both the railroad companies and the regulators; it would not only facilitate mitigation of public risk, but also translate into better insurance rates and cleaner public image for the railroad companies, and fewer catastrophic episodes involving casualties for the regulators. Additionally, it would provide growth opportunities that are of interest of both corporate and regulatory players. To assess the effectiveness of this strategy, we conduct a Cost Benefit Analysis, which evaluates the maximum possible risk reduction as a function of the investment budget. While this analysis can be done from a central decision maker's perspective, the possibility of a regulator-industry cooperation in financing and building tracks is considered. We employ Cooperative Game Theory to propose a fair and stable coalition. Such a coalition would allocate investment costs to three main players, i.e. regulator and two major railroad companies in the country.

2 - Customer lifetime value modeling and revenue management
Mikhail Nediak, Akram Khaleghei, Ivan Sergienko

In various industries, a key challenge is to accurately assess client's lifetime value (CLV) across multiple products and develop analytical methods capable of maximizing revenue while meeting customer needs. CLV models have the potential to inform management decisions on client strategy, resource allocation, and pricing. We have developed mixed effect regression models to predict the expected revenue of customer using his past purchase behavior, cross-buying effects, and market information. We use these models to build Monte Carlo simulations to project client's long-term expected value. Our results and findings will guide future marketing decisions for a company that offers several types of products to prioritize clients based on their contributions to the profitability of the company as well as optimal resource allocation and monitoring the impact of management strategies on the value of customer assets. We apply our model to capital market products in the financial services industry.

3 - Dynamic pricing of the fixed-term subscription contract offered to the strategic customers
Roozbeh Yousefi, Jue Wang, Yuri Levin, Mikhail Nediak

Subscriptions are contracts that a company makes with its customers for regular service delivery or for providing access to the service. Service access limits can be stipulated in the subscription contract. We present a continuous time dynamic pricing model for a monopolist offering a fixed term subscription contract without per-use charges to strategic customers. We formulate the monopolist's problem in terms of optimal control, derive its optimality conditions, and study the structure of the optimal solution. We also examine the stationary optimal pricing regime and evaluate it in numerical experiments.

■ FA-20

Friday, 8:30-10:00 - 2103

Dynamical models in sustainable development 4

Stream: Dynamical models in sustainable development
Invited session
Chair: *Chi-Tai Wang*

1 - Faster or safer
Miao He, Shuo Xu, Xinyao Qu, Xiangguan Liu, Ying Kong

In order to evaluate and enhance the traffic efficiency, in this paper, we propose a set of solutions through mathematical modeling. Firstly, two matrix models for description of the traffic states within four lanes are provided. One is a position matrix. While the other model is a velocity matrix. Then we analyze the characteristics of these two matrixes under heavy or light traffic condition.Secondly, we use integral expressions to build an overtaking model which is also a model to optimize the traffic flow at the meantime, and set the objective function as to minimize the time spent on overtaking. Next, we compare the traffic efficiency with or without the extant rule through a simulation, and validate that the extant rule do improve traffic flow to some degree, although not remarkable.Thirdly, we explain the inter-relationships among factors, such as traffic flow and safety through theoretical models and calculations. And we attempt to achieve a trade-off by bringing forward four alternative rules: exchanging lanes, enhancing the speed limits, changing the lanes along with odd and even months and setting a reversible lane. Moreover, we contrast the strengths and weaknesses of these rules through simulating on computers.Then,we perform sensitivity analysis to assess the performance of our rules.Finally,we develop a multi-layer network model with consideration of features of Intelligent Vehicles (IV) to realize the intellectual control.

2 - The impacts of load management of electric vehicles fleets under uncertainty
Katrin Seddig, Patrick Jochem, Wolf Fichtner

Electric vehicles (EV) represent one of the most promising technologies towards sustainable and green transport system. The integration of local power generation by renewable energy sources (RES) through charging coordination of EVs could enhance their potential. However, not only the RES have an intermittent character but also there is a stochastic characteristic of the EV loads. Hence, a careful consideration of the dynamic interaction between these two green solutions seems to be attractive. This paper addresses the impacts of charging strategies of different EV fleets with a common charging infrastructure considering uncertainty and its possible policy implications. The application field is a public charging infrastructure in a parking garage which is modeled in a simulation platform. Various scenarios with fluctuating generation of electricity by RES, individual electricity demand, restrictions and parking times of EV fleets are applied within a simulation approach and compared with different scenarios of an optimization model. Hereby, stochastic programming is used to particular integrate uncertainties in deviations from planned and realized RES generation as well as electricity demand by the EVs. Numerical results are presented and derived from this possible business models for a parking garage operator as in a role of an aggregator of EVs are developed.

3 - Two-stage stochastic programming model of building clusters combined cooling, heaing and power system based on CVaR
Xiaolin Chu, Dong Yang, Xiaohong Li

In the recent years, the energy efficiency problem of building clusters has received much attention with the sustainable development around the world. The building clusters with combined cooling, heating and powerCCHPsystem is one of critical ways to reduce building clusters' energy consumption. As a result, the optimal operation of CCHP-based building clusters becomes crucial. However, few researches take the uncertainties, such as load demand and energy price, into account when the CCHP-based building clusters are addressed. To handle this problem, a two-stage stochastic programming model is formulated for the CCHP-based building clusters and the Conditional Value at RiskC-VaRis utilized to measure the model risk. The stochastic model is transformed into its deterministic equivalent model, which is a non-linear mixed integer programming model. In order to solve the established optimization model efficiently, linearization technology and improved Benders algorithm are applied. Finally, the numerical experiments are conducted to illustrate the efficiency of the algorithm. In addition, the results show that the system's economic benefits cannot exactly attained without taking account into the uncertainties.

4 - Identifying an optimally configured solar/wind power system for buildings
Chi-Tai Wang

As reported by United Nations Environment Programme and many academics, buildings consume a major amount of energies, which implies that they are a major emitter of greenhouse gases. Therefore, it is clear that reducing the energy needs of buildings is playing a critical role in our fight against global warming. Adopting solar or wind energy has become a popular option for buildings to reduce their energy dependency on the grid. And normally, some simulation-based software is used to evaluate an appropriate configuration for the solar/wind power generation system, before such a system is actually installed at the subject building. Nevertheless, the latest solar/wind power technologies have created a challenge to these simulation tools, and the reason is the creative design and functions of these new technologies—they have made the planning task highly combinatorial optimization in nature. Therefore, this contributed presentation will introduce a strategic planning approach developed to appropriately address the aforementioned challenge. This approach is capable of considering conventional and the latest renewable energy technologies simultaneously and can provide promising system configurations for simulation-based tools to conduct detailed evaluations.

■ FA-22

Friday, 8:30-10:00 - 2104B

Applications of OR 6

Stream: Applications of OR (contributed)
Contributed session
Chair: Antoine Jouglet

1 - Internal logistics operations process design
Hasan Yavuz

This project's main objective is focusing through the material handling process's problems in warehouse that observed by company and project team. The main aim of this project is to eliminate them with new models and system design for warehouse and other logistics operations. There are 3 different main problems in material handling processes which are imbalanced workload among the order pickers (O.P.), ambiguous order picking sequencing and tardiness between due date and delivery time of materials. For imbalanced workload between O.P. and ambiguous order picking sequencing, two different math. models are proposed to approach these problems. First model will be an Assignment Model and the second one will be about Scheduling Model. Assignment model will decrease the imbalanced workload and scheduling model will eliminate the ambiguous order picking sequence so it will decrease the amount of delayed transfers but not eliminate. For the tardiness in the material handling, a new system design is suggested. In the current systems, order pickers are assigning to the project at the beginning of each year and they respond to the orders of the projects that they are assigned, this is called dedicated system. It is planned to make pool system for the material handling process. This new pool system may directly eliminate the imbalanced workload of the O.P will not receive different orders in short time period. This system will divide orders equally between all O.P .

2 - The speed meeting problem
Antoine Jouglet, Benoît Cantais, David Savourey

In a speed meeting problem, people are gathered in a place where tables are disposed to meet each other. The set of persons that each person wishes to meet is known. At regular intervals, the persons are asked to get up and are redistributed among the tables. A distribution of the persons among the tables is called a round. Given a number of rounds, the goal is to distribute the persons around the tables at every round to maximize the total number of wished meetings realized. As far as we know, this problem has not been treated yet. In this talk, we present a branch and bound method to find the optimal solution to the speed meeting problem : at every branch of the search tree, a round number is assigned with a wished meeting between two persons. The table where the meeting takes place is not specified. We construct and solve a Bin-Packing problem to check if the meetings assigned with a round are feasible. We introduce a set of dominance rules that can be used with this model and we show how to compute an upper bound relying on the construction of a flow network and the resolution of a maximum flow problem. We present preliminary results based on a set of crafted instances and we discuss the efficiency of the branch and bound algorithm using this upper bound method compared with other approaches.

■ FA-23

Friday, 8:30-10:00 - 2105

Integrated planning in public transport

Stream: Optimization for public transport
Invited session
Chair: Richard Lusby

1 - Integrated duty assignment and crew rostering
Thomas Breugem, Twan Dollevoet, Dennis Huisman

In this talk we consider the rostering of personnel at Netherlands Railways (NS), the main railway operator in the Netherlands. A main part of the overall planning process at NS is the Crew Planning process, i.e., assigning the set of tasks to the employees. Many complex labor rules have to be taken into account during this planning phase. Crew Planning at NS is solved in three phases: Crew Scheduling, Duty Assignment and Crew Rostering. The Duty Assignment problem consists of finding a 'fair' allocation of the duties among the roster groups. The Crew Rostering problem is well known in literature, and consists of finding good rosters given a set of duties. In the current approaches these problems are solved sequentially, although some interaction is present (e.g., adding constraints to assure a high chance of feasibility in the next phase). Our main contribution is an integrated model for the Duty Assignment and Crew Rostering problem. We propose a heuristic solution method based on Column Generation. We also demonstrate the benefit of our integrated approach on practical instances from NS.

2 - Integrated bus driver rostering and days off scheduling
Safae Er-Rbib, Guy Desaulniers, Issmail El Hallaoui

We consider the problem of assigning duties and days off simultaneously to bus driver rosters in order to balance as much as possible the weekly working time among the rosters while satisfying various working rules concerning mostly the rest periods between two working days, and the number of days off per week. We model this problem as an integer program and we report computational results obtained on real-world instances.

3 - A new exact algorithm for line planning and shuttle planning
Evelien van der Hurk

This work presents a new method for solving line planning and shuttle planning problems. Line planning concerns the problem of selecting a set of lines and frequency to serve the demand in a public transport network at a good balance between provided passenger service and operation costs. In this, a line represents a vehicle visiting an ordered set of stops. The presented method is aimed to provide a more scalable approach to solving line planning problems with 1) dynamic passenger assignment; 2) frequency dependent passenger costs; and 3) the possibility to include a minimum frequency constraint conditional on the opening of a line. The proposed exact algorithm starts from a simple representation of the public transport network where the frequency dependent vehicle capacity requirements and passenger costs are relaxed; next the algorithm iteratively solves the relaxed problem and tightens these bounds until the optimal solution is found. In the worst case, the algorithm continues until a full representation of the network is reached, which would not provide a speed-up. However the expectation is that for most practical cases feasible solutions are found after few iterations, thus increasing computational speed and tractability of realistically sized problems. The method is applied to a case study for shuttle bus planning for the Danish railway.

4 - Integrating rolling stock scheduling with train unit shunting
Richard Lusby, Joergen Haahr

In this talk, we consider integrating two important railway optimization problems, in particular the Rolling Stock Scheduling Problem and the Train Unit Shunting Problem. We present two similar branch-and-cut based approaches to solve this integrated problem and, in addition, provide a comparison of different approaches to solve the so-called Track Assignment Problem, a subcomponent of the Train Unit Shunting problem. In this analysis we demonstrate, by way of a counter example, the heuristic nature of a previously argued optimal approach. For the integrated problem we analyse the performance of the proposed approaches on several real-life case studies provided by DSB S-tog, a suburban train operator in the greater Copenhagen area. Computational results confirm the necessity of the integrated approach; high quality solutions to the integrated problem are obtained on instances where a conventional, sequential approach ends in infeasibility. Furthermore, for the considered instances, solutions are typically found within a few minutes, indicating the applicability of the methodology to short-term planning.

■ FA-24

Friday, 8:30-10:00 - 301A

OR in healthcare

Stream: CORS SIG on healthcare
Invited session
Chair: Dmitrii Usanov

1 - Real time dispatching strategies for intrahospital transportation requests
Angel Ruiz, Jose Eduardo Pecora, Cassius Scarpin

Given a set of transportation requests and a set of available resources (stretchers), managing intrahospital transportation activities consists in electing simultaneously the request to perform and the resource (stretcher) to perform it. Managers may pursue efficiency oriented objectives such as minimizing the total distance travelled by stretchers, or patient service oriented ones, like for example, minimizing the requests' longest waiting time or even minimizing the average requests' longest waiting time. In its static version, the set of requests is given in advance, and the problem can be modelled as a parallel machines scheduling problem with sequence-dependent setup times, where the setup times represent the time required for a stretcher to move from the ending location of a request to the starting location of its next task. But in the more realistic dynamic version, the set of requests can change with the unpredictable arrival of new requests, which makes of this problem a real time decision one. We deal with such a difficult context in the following way. At each event (the arrival of a new requests) the schedule for all the waiting requests is reconsidered. To this end, a mathematical model formulated as a Mixed Integer Linear Programming (MILP) is used to minimize the makespan. We also propose to reschedule the unprocessed tasks by several heuristics methods. The performance of the different methods is assessed on real-life instances.

2 - Fire truck relocation during big incidents
Dmitrii Usanov

The positioning of the fire stations and dispatching of the fire trucks is designed to allow for a quick response, irrespective of the location of the incidents. However, when a substantial fraction of the fire fighting capacity is occupied, significant gaps in coverage may arise. It is standard practice of fire departments to close the gap in coverage by temporarily relocating fire trucks. However, relocation is done largely based on intuition. As we demonstrate, not relocating during big incidents, or relocating based on flawed heuristics and intuition, may lead to significant performance degradation. We consider the situation where a big incident just happened, and fire trucks are pulling out to respond to the incident. We propose an algorithm to compute the optimal relocations. A certain requirement to the coverage is imposed that is aimed at keeping a fairly uniform distribution of available trucks over the area. If this requirement is violated, the algorithm makes relocations by solving a mathematical program that takes into account the location of the available fire trucks and the historic spatial distribution of incidents. We apply the algorithm to the operations of the Amsterdam-Amstelland Fire Department, and examine it against three other benchmark strategies. We demonstrate a substantial improvement over current practice, and reaffirm the importance of doing relocations by showing a significant reduction in the response time compared to not relocating at all.

■ FA-25

Friday, 8:30-10:00 - 301B

Healthcare services

Stream: Healthcare services
Invited session
Chair: Rui Oliveira

1 - Clustering the Portuguese hospitals based on their activity, effectiveness and external environment
Rui Oliveira, Diogo Ferreira, Rui Marques, Marta Castilho Gomes

Financing healthcare services in an efficient and effective way plays a pivotal role on their sustainability. In the particular case of Portuguese public hospitals, these entities are mainly financed by means of the so-called Beveridge model, i.e. through taxes. Resources are then allocated using a set of not-so-clear criteria. Allegedly, public hospitals are clustered into different groups in a basis of their own dimension and case-mix and paid prices per activity are different between groups. Coupled with the fact that this process is not transparent, wrong resources allocations may induce the public entities indebtedness increasing over time. The present work aims at contributing to overcome this problem by employing some well-known multivariate statistical techniques exploring a set of forty-nine variables (including hospitals' activity, quality and external environment) on twenty-seven public hospitals, in order to obtain the best set of clusters embodying all of those features. Results robustness is also analyzed by using a set of different well-known criteria.

2 - Investigation of patient concentration phenomenon in emergency departments considering transportation costs
Minjae Kim, Jungwoo Cho, Yoonjin Yoon

Patient concentration to large-sized hospitals has been a problem in Korea in recent years. The same problem lies in prehospital Emergency Medical Services (EMS) in highly urbanized city of Seoul; it is known that patients prefer emergency departments of large-sized hospitals, expecting a better care and a faster admission. This concentration phenomenon is possible because of large number of available options that patients can choose from. The objective of this study is to examine the hospital choice of emergency patients by comparing the cost of choosing the actual and alternative options. We define and measure the proximity index of emergency hospitals that are accessible by patients transported by ambulance within a specific travel time threshold. We utilize the actual incident locations and road networks to calculate the routing of ambulances and corresponding travel times using Geographic Information Systems (GIS). The proximity index is calculated and compared within hospitals, age groups, conscious states, and disease subgroups. The results show that one of the biggest hospitals in the city is preferred by people although the cost of choosing is approximately a double of the overall average and that non-urgent patients tend not to choose the best option. This study suggests that efficient decision making in prehospital EMS may contribute in relieving the patient concentration in emergency departments.

3 - On the optimal routing and vehicle scheduling for emergency-home-healthcare problem
Juan Sebastian NiÑo Rivera, William Guerrero

Home-healthcare logistics for medical emergencies is a challenge for Operations Research. Consider a set of ambulances and medical support vehicles located in specific points (ambulance bases) distributed over a geographic area at a given moment of the day. These ambulances will, when needed, go to the patients' location to provide medical services. We consider that ambulances can only serve a single patient at a time. In some cases, high priority patients require to be transported to a hospital immediately. Other times, non-priority patients are visited and treated at home. We address the problem of sequencing the ambulances to visit the set of patients which may have different levels of priority. The objective is to find the set of routes that visit every patient location with the minimum weighted average arrival time at patients' locations as a service level indicator. A Mixed Integer Linear Programming model is proposed and it is denoted as the Open-Arc-Multi-Traveling-Salesmen-Problem with cumulative objective function (Cumulative OAMTSP). This problem can be classified as an operational planning problem in home health care logistics as it is related to short-term decisions that need to be made several times a day. We analyze different priority ranking models related to the gravity of injury of the patients and conclude how the ranking scale may impact the routing decisions by making analysis on several randomly generated scenarios.

■ FA-26

Friday, 8:30-10:00 - 302A

OR in agriculture 3

Stream: OR in agriculture
Invited session
Chair: *Sergio Maturana*

1 - Assessing the effects of variability and capacity tightness on the performance of labeling postponement for an export-winery under demand uncertainty
Sergio Maturana, Mauricio Varas, Susan Cholette, Alejandro Mac Cawley

Export-oriented wineries face a challenging task when planning their bottling and labeling operations. Wineries that export to many markets must be able to meet the different labeling requirements of each of them. To avoid having to carry inventory for too many SKUs, some wineries postpone bottling until they receive an order from one of the markets they receive, while others only postpone labeling, which is usually faster than bottling. Although postponing only labeling allows more flexibility, since the same unlabeled bottle may be used for any market, it requires additional handling of the bottles. Therefore, unless the benefit of labeling postponement is significant, it is better to bottle and label directly. To assess the benefits of labeling postponement, a multi-stage mixed-integer stochastic programming model with full recourse for demand scenarios for planning wine production was developed. This model was used to simulate the operation of the winery under different conditions of capacity and demand uncertainty. The results of the numerical experiments showed that postponed labeling outperforms bottling and labeling when capacity is tight. Conversely, when production line capacity is only loosely constrained, labeling postponement loses most advantages over bottling and labeling, save for when forecasts are highly inaccurate. Results are mixed when capacity is moderately constrained, but postponement's advantages increase when there are less accurate forecasts.

2 - Operations research techniques for location of grain silos in Paraná State, Brazil
Maria Teresinha Arns Steiner, Pedro Steiner Neto, Dilip Datta, José Rui Figueira, Cassius Tadeu Scarpin

Soybean and corn production has increased steadily in Brazil and Paraná State is the second largest producer of these grains in the country. The increased production has now necessitated to increase the storing facility also. Accordingly, partitioning the storage is a proposal to aggregate the municipalities of Paraná into regions as a way of facilitating production and transportation of the grains. Motivated by the requirement, this paper aims to organize the storage regions of Paraná by modeling its municipalities as a multi-objective graph (territory) partitioning problem with the municipalities being the nodes and roads linking them as the edges of the graph. In order to find the effective number of new silos to be constructed and region-wise their locations, maximization of the homogeneity of storage deficit and minimization of the distances from production sources to storage points are considered as two objective functions of the problem. A multi-objective genetic algorithm based results, presented here, should have a strong impact on the grain storage system management in Paraná.

3 - Agricultural production programming in small funds in Colombia
Leonardo Talero, Edwin Garavito, Eliana Peña

The United Nations has proposed the sustainable development goals with the aim of improving the people life quality with environmental sustainability as a request for finish the poverty, protecting the planet and ensuring development, peace, and prosperity. Consequently, an important goal is end hunger, achieve food security and improved nutrition and promote sustainable agriculture; supporting the people-centred rural development and protecting the environment. For this, it is necessary to generate models, frameworks, and methodologies that guide agricultural producers in the processes development aligns with the United Nations goals, as a base for food security. This demand in addition to tropical countries economics characteristics -as those observed in Colombia-, with a high economic dependence on the growth sector, configured principally by small agricultural production with high poverty levels request special focus. The present work proposes a strategy to facilitate agricultural production in Colombia, with the aim of covering the estimated nutritional requirements for productive units, thus increasing their food resilience.

■ FA-27

Friday, 8:30-10:00 - 302B

Advances in mine planning 2

Stream: OR in mining
Invited session
Chair: *Amina Lamghari*

1 - Short- and medium-term optimization of task scheduling for underground mines
Louis-Pierre Campeau

Applications of operations research to short-term underground mine scheduling are very few, mostly because of the complexity and specificity of its constraints. These include numerous resource limitations, congestion problems and complex precedence network. This presentation will discuss the advances made with a model for short- and medium-term scheduling in large underground mines. The results of the model application to real-world and fictional data sets will be explained. A robust variation of the model and its advantages will also be described. Comments on future work and possibilities in this field will conclude the presentation.

2 - A mathematical formulation for practical pushback design
Juan Luis Yarmuch, Marcus Brazil, Doreen Thomas, Joachim Rubinstein

Open pits are surface excavations made to extract valuable material (ore) from the earth. In general terms, the ore is located below the surface and non-valuable material must be removed before reaching the ore. Traditional mine planning process starts by defining the ultimate pit limit (UPL), which is the contour of the excavation that maximises the mining profit. Then, the UPL is subdivided into manageable mining units called pushbacks (also known as mining cuts or mining phases) which are mined to feed the processing plants. In the industry, practical pushbacks are considered as workable volumes that contain an amount of ore equivalent to 1-3 years of plant production. Besides considering wall slope constraints, workable pushbacks need to, first, satisfy a minimum width to allow safe operation of the mining equipment, and, second, have at least one haulage ramp to access the pushback from top to bottom. Traditional models of pushback design avoid the complexity of the workability constraints. As a consequence, most of the output from these models requires significant intervention by mining engineers. This work presents a new formulation to generate maximum profit practical pushbacks. A designability factor is introduced to measure the performance of different pushback formulations. Finally, a set of numerical experiments shows that our formulation performs better than traditional approaches, reducing the engineer's intervention needed to generate practical designs.

3 - A new algorithm for a multi-product open pit mine scheduling problem
Zeyneb Brika, Michel Gamache, Roussos Dimitrakopoulos

This paper studies the multi-product scheduling problem in an open pit mine. This involves determining which blocks will be extracted during each period and what to do with them once they are extracted choosing from among a given set options. Aside from the precedence constraints that impose a mine must be extracted from the surface on downwards, the problem is subject to side-constraints such as the resource or blending constraints, among others. Typically, long-term production planning problems in the mining industry have a relatively limited number of side constraints but millions of variables and tens of millions of precedence constraints. Despite the large scale of the optimization model, mining scheduling problem present a particular structure from which we take profit to develop an efficient solution method presented in the paper. This method is an iterative algorithm essentially based on Lagrangian relaxation and column generation. Besides, unlike traditional approaches that use cut-off grades, we use coalition formation clustering to define where the material is sent. Thus, the variables that directly affect blending targets are taken into account during the optimization process which leads necessarily to better results. Computational experiments will be presented in the last section.

4 - A stochastic optimization method with in-pit tailings dispoal for the open pit mine planning problem

Adrien Rimélé, Michel Gamache, Roussos Dimitrakopoulos

Long term mine planning is governed by three key factors: cost optimisation, risk management and environmental sustainability. A component of the latest concerns waste and tailings storage: the required stockpiles occupy a considerable space having several consequences and constraints. The available space for storage can be limited because of the topography and the facilities. Produced volumes will deeply impact the landscape and local environment by their size and chemical properties. Finally, during the rehabilitation phase, re-handling this material will imply an additional cost. This work presents a new MIP formulation to model in-pit waste and tailings disposal during the operations for a particular low dip iron ore deposit in Northern Quebec. The model is incorporated into a two-stage stochastic framework which aims to optimize the expected NPV while controlling geological uncertainty using stochastic simulations. The proposed formulation includes numerous imposed constraints such as spatial continuity of the in-pit disposal; an increasing evolution of the disposal area; predecessors and successors constraints for both extracted and stored materials; valuable ore accessibility request. The complexity of the model was tackled with a sliding time window heuristic method with grouped periods, which resulted in an optimality gap of 1.76%. The results confirm the model's risk resilience and the potential of considering in-pit storage for both cost and space savings.

■ FA-28

Friday, 8:30-10:00 - 303A

Modeling and optimization of oil production and processing systems

Stream: OR in the oil and gas sectors
Invited session

Chair: *Eduardo Camponogara*
Chair: *Vladimir Mahalec*
Chair: *Bora Tarhan*

1 - Adjoint-based optimal control of well settings using function control parameterization

Nadav Sorek, Hardikkumar Zalavadia, Eduardo Gildin

Water injection into subsurface reservoirs is the most widely used method to produce oil. The method, also called water flooding or secondary recovery, increases the pressure and thereby stimulate production. The water is injected from a set of injection wells, and the total liquid (oil and water) is produced from a set of production wells. A reservoir management strategy to maximize the long-term profit attempts to find the optimal control of the water flooding campaign. The control variables of the wells are usually either pressure, flow rate or choke valve position, determined over a time horizon. A direct method parameterizes the control trajectory and cast the original infinite dimensional optimization problem into a finite solution space. The problem is then solved using reservoir simulation and NLP optimization method, which is computationally expensive. In this work, we present a control parameterization method utilizing function approximations. Using synthetic two-dimensional and realistic three-dimensional reservoirs, we show that function approximation captures the infinite dimensional solution with less number of coefficients compared to the traditional piece-wise constant parameterization. Additionally, in order to obtain the gradient of the objective function with respect to the parameterization variables, we derive the adjoint method for an arbitrary control function.

2 - Crude unit model for planning, scheduling, and optimization of operations

Vladimir Mahalec, Gang Fu, Pedro Castillo Castillo

Crude distillation unit (CDU) is the first processing unit in the refinery. It separates the crude feed into streams which are either used for product blending or are processed further in the downstream units. If CDU model predicts inaccurate yields or properties of its products, then the feeds to the downstream process units will be inaccurate, which will lead to non-optimal blending when compared to the actual operation. This work evaluates the impact of different types of CU models on planning and optimization of operations. We present recently developed hybrid model (approx. 200 mostly linear equations) of CDU. The model uses operating conditions and feed properties to predict product TBP curves with less than 1% error with respect to CDU predictions by the rigorous simulations. Optimization of CDU operations shows that the hybrid model leads to an optimum which is better than the one computed by equation oriented optimization of the rigorous model in AspenPlus. The same CDU model has been used to optimize refinery production plans and compared by the plans computed from models based on swing cut and swing cut + bias. Higher accuracy of the hybrid model leads to the production plans or feedstock purchases which are significantly different from those computed via the swing cut models. Differences in the computed optima point towards more accurate planning models as a very fruitful path to increase the refinery profitability.

3 - A large-scale stochastic programming model for shale gas artificial lift infrastructure planning

Selen Cremaschi, Zuo Zeng

Artificial Lift Methods (ALMs) are important for the long-term profitability of oil and gas producing wells. Because large amounts of fluid are injected to the shale formation during the fracturing process, shale-gas wells often require deliquification to unload the well relatively quickly, generally within their first or second year of production. Typical lifetime of a well is around 20-25 years, and hence, multiple ALMs may be installed in horizontal wells for achieving desirable production performance. We present a multi-stage stochastic linear programming (MSLP) model for artificial lift infrastructure planning (ALIP) of shale gas producing horizontal wells. The model determines which ALM(s) should be installed, and their installation and operation plan. The MSLP model incorporates highly stochastic nature of the ALM-dependent well production, which is an endogenous uncertainty. The objective is to maximize the expected net present value of the well for its lifetime. Finally, we use the MSLP model to generate ALIP for a horizontal well located in Woodford shale.

4 - Network constrained reservoir optimization

Eduardo Camponogara, Thiago Silva, Andres Codas, Milan Stanko, Bjarne Foss

A methodology is proposed to optimize the recovery of petroleum reservoirs constrained by production gathering systems. Since full-field implicit simulations are prohibitively costly, reservoir management policies are typically developed with standalone reservoir models, while constraints with respect to the production gathering network are limited or fully disregarded. However, it is well known that the field operation is driven by platform settings and constraints imposed by the network and processing facilities. Therefore, the disregard of such constraints may render unfeasible operational plans in practice, precluding their application in real-world fields. In this work, we propose to optimize oil reservoirs constrained by gathering networks with a multiple shooting formulation, which is a control method suitable for problems with numerous output constraints. This method splits the prediction horizon of the optimal control problem in several smaller intervals enabling the use of decomposition and parallelization techniques. The developed methodology is assessed in a two-phase black-oil reservoir producing to a gathering network with nonlinear constraints regarding the operation of electrical submersible pumps. To demonstrate the method's capability to handle network constraints, the results of the network constrained approach are contrasted against the conventional unconstrained approaches.

■ FA-29

Friday, 8:30-10:00 - 303B

Machine learning for applications

Stream: Long term planning in energy, environment and climate
Invited session
Chair: *Gilles Guerassimoff*
Chair: *Burak Cankaya*

1 - Understanding tank cleaning time by utilizing geospatial data and machine learning techniques
Burak Cankaya

GPS devices give signals that define their locations and other features with a timeframe. These devices can be found on cellphones, cars, vessels, trains, and planes. When the data for a specific area evaluated it is commonly seen on the map that the vehicle moves between points. In order to understand the movements of vehicles, the vehicle movement patterns should be understood. This research is one of the pioneer studies that labels the vehicle movements with activities and makes it possible to track the activities of moving flocks. The research compares various machine learning algorithms including but not limited to Artificial Neural Networks (ANN), K- Nearest Neighbour, K-Means algorithms. The end result of the research is a valuable tool for the transportation industry. The research will be demonstrated on a case study on Tank Cleaning Time of Chemical Vessel by Utilizing Geospatial data which is an unknown operation time for the maritime transportation industry.

2 - Pump scheduling in drinking water distribution systems through convex relaxation and time step duration adjustment
Gratien Bonvin, Sophie Demassey

The pump scheduling problem in drinking water distribution systems aims to minimize the electrical costs due to pumping while ensuring the supply of water to end-consumers. Recently, new interests concerning this problem have been observed because drinking water networks seem well-suited for taking advantage of new electricity markets such as spot markets and secondary electricity grid regulation, because of their water storage ability and the flexibility in the pumping operation. However, the optimal control of a drinking water distribution system remains complex because it relies both on discrete decision such as switching pump on and off, and nonlinear constraints for the description of pressure-related physical laws. By arguing that the non-convex constraints tend to be fulfilled because of the shape of the objective function, even if we don't take them into account, we propose to approximate the non-convex constraints by their convex hull. Then, a feasible solution is recovered by adjusting the time steps duration. Applications to two networks previously studied and comparison with proposed methods are presented in order to highlight the relevance of our solution.

■ FA-30

Friday, 8:30-10:00 - 304A

Sustainable operations

Stream: Sustainable living: Cognitive, social, economical, ecological and world view
Invited session
Chair: *Gonzalo Romero*
Chair: *Gerhard-Wilhelm Weber*
Chair: *Andre Calmon*

1 - Increasing the quality of agricultural production in developing countries
Andre Calmon, Sameer Hasija, K. Sudhir

Intermediaries play an important role in traditional agricultural supply chains in emerging and underdeveloped markets. However, these intermediaries are considered a source of inefficiency in the supply chain as they may introduce agency issues such as holdup and moral hazard. Motivated by observations from the agricultural supply chains in emerging markets, in particular in India, we study the role of different intermediary channel structures in eliminating/attenuating the loss of efficiency in this supply chain. More specifically, we focus on how quality, prices, and farmer effort are influenced by competition and technology availability among intermediaries.

2 - Consumer education and regret returns in a social enterprise
Gonzalo Romero, Andre Calmon, Diana Jue-Rajasingh, Jackie Stenson

We study the problem faced by a social enterprise that distributes new life-improving technologies in a developing market. Its goal is to profitably increase the adoption of a product that is sold through a small retailer. The retailer sells to risk-averse consumers that have an uncertain product valuation. The distributor considers two scale-up strategies: (i) improve the information accuracy provided to consumers, and (ii) improve its reverse logistics which supports higher refunds for regret-returns. Our model incorporates regret-returns, information control, and the value of satisfied customers. We find that (i) and (ii) are strategic substitutes. More importantly, we show that if the distributor highly values product adoptions by satisfied customers, it will prefer to pursue reverse logistics rather than improving information accuracy. This suggests that reverse logistics are effective in increasing product adoptions. This insight is robust to different model specifications that lead to qualitatively different retailer behavior.

Friday, 10:30-12:00

■ FB-03

Friday, 10:30-12:00 - 200AB

Closing session

Stream: Plenary sessions
Invited session

STREAMS

2017 IFORS prize for OR in development

Mikael Rönnqvist
Département de génie mécanique
mikael.ronnqvist@gmc.ulaval.ca
Track(s): 9

Algorithmic nonsmooth optimization and differential equation solving

Andreas Griewank
yachaytech
griewank@yachaytech.edu.ec
Track(s): 10

Algorithmic/computational game theory

Michal Feldman
Tel Aviv University
mfeldman@post.tau.ac.il

Michal Feldman
Tel Aviv University
michal.feldman@cs.tau.ac.il
Track(s): 14

Applications of dynamical models

Alberto Pinto
University of Porto
aapinto1@gmail.com
Track(s): 15

Applications of heuristics

Lukas Bach
Sintef Ict
lukas.bach@sintef.no

Geir Hasle
Sintef Ict
geir.hasle@sintef.no
Track(s): 1

Applications of MCDA

Theodor Stewart
University of Cape Town
Theodor.Stewart@uct.ac.za
Track(s): 13

Applications of OR (contributed)

Track(s): 22 28

Behavioural OR

L. Alberto Franco
Loughborough University
L.A.Franco@lboro.ac.uk

Raimo P. Hämäläinen
Aalto University, School of Science
raimo.hamalainen@aalto.fi
Track(s): 27

Biomass-based supply chains

Magnus Fröhling
TU Bergakademie Freiberg
magnus.froehling@bwl.tu-freiberg.de

Taraneh Sowlati
University of British Columbia
taraneh.sowlati@ubc.ca
Track(s): 30

Business analytics

Dries Benoit
Ghent University
dries.benoit@ugent.be

Kristof Coussement
IESEG School of Management
k.coussement@ieseg.fr

Wouter Verbeke
Vrije Universiteit Brussel
wouter.verbeke@vub.ac.be
Track(s): 19

City logistics and freight demand modeling

Jose Holguin-Veras
Rensselaer Polytechnic Institute
jhv@rpi.edu
Track(s): 8

Combinatorial optimisation

Rosiane deFreitas
Ufam / Ufrj
rosiane@icomp.ufam.edu.br

Nelson Maculan
Universidade Federal do Rio de Janeiro
maculan@cos.ufrj.br
Track(s): 14

Computational biology, bioinformatics and medicine

Jens Allmer
Izmir Institute of Technology
jens@allmer.de

Pedamallu Chandra Sekhar
Dana-Farber Cancer Institute
pcs.murali@gmail.com

Gerhard-Wilhelm Weber
Middle East Technical University
gweber@metu.edu.tr
Track(s): 28

Constraint programming

Track(s): 22

Continuous optimization (contributed)

Track(s): 15

Control theory, system dynamics (contributed)

Track(s): 17

Copositive and conic optimization

Immanuel Bomze
University of Vienna
immanuel.bomze@univie.ac.at
Track(s): 13

CORS practice prize

Mikael Rönnqvist
Département de génie mécanique
mikael.ronnqvist@gmc.ulaval.ca
Track(s): 6

CORS SIG on forestry

Taraneh Sowlati
University of British Columbia
taraneh.sowlati@ubc.ca
Track(s): 9 25

CORS SIG on healthcare

John Blake
Dalhousie University
john.blake@dal.ca

Michael Carter
University of Toronto
carter@mie.utoronto.ca

Peter Vanberkel
Dalhousie University
peter.vanberkel@dal.ca

Track(s): 24

CORS SIG on queueing theory

Steve Drekic
University of Waterloo
sdrekic@math.uwaterloo.ca

Track(s): 2

CORS student paper competitions

Track(s): 6

Cutting and packing

A. Miguel Gomes
Universidade do Porto - Faculdade de Engenharia
agomes@fe.up.pt

José Fernando Oliveira
University of Porto, Faculty of Engineering
jfo@fe.up.pt

Track(s): 21

Data driven modeling in operations management

Soheil Sibdari
University of Massachusetts
ssibdari@umassd.edu

Track(s): 19

Data science and analytics (contributed)

Track(s): 2 8 18

DEA applications

Ana Camanho
University of Porto
acamanho@fe.up.pt

Meryem Duygun Fethi
University of Leicester
m.fethi@le.ac.uk

Vania Sena
University of Essex
vsena@essex.ac.uk

Track(s): 17

Decision analysis

Erin Baker
U. Mass Amherst
edbaker@ecs.umass.edu

Juuso Liesiö
Aalto University
juuso.liesio@aalto.fi

David Rios Insua
Royal Academy of Sciences of Spain
david.rios.insua@gmail.com

Track(s): 8

Decision making modeling and risk assessment in the financial sector

Cristinca Fulga
Bucharest University of Economic Studies
fulga@csie.ase.ro

Track(s): 1

Decision support systems

Adiel Teixeira de Almeida
Universidade Federal de Pernambuco - UFPE
almeida@cdsid.org.br

Oluwafemi Oyemomi
Northumbria University
oluwafemi.oyemomi@northumbria.ac.uk

Pascale Zaraté
Toulouse Capitole 1 University
zarate@irit.fr

Track(s): 16

Derivative-free optimization

Ana Luisa Custodio
Universidade Nova de Lisboa
alcustodio@fct.unl.pt

Track(s): 4

Design and management of manufacturing systems

Olga Battaïa
ISAE Supaero
olga.battaia@isae.fr

Alena Otto
University of Siegen
alena.otto@uni-siegen.de

Track(s): 2

Discrete optimization - Computational methods

Cole Smith
University of Florida
jcsmith@clemson.edu

Track(s): 17

Discrete optimization in logistics and transportation

Ivan Contreras
Concordia University
icontrer@encs.concordia.ca

Jean-François Cordeau
HEC Montréal
jean-francois.cordeau@hec.ca

Track(s): 1 9

Discrete optimization, mixed integer programming (contributed)

Track(s): 22

Dynamic programming

Lidija Zadnik Stirn
University of Ljubljana
lidija.zadnik@bf.uni-lj.si

Track(s): 5

Dynamical models in sustainable development

Pierre Kunsch
Vrije Universiteit Brussel
pkunsch@vub.ac.be

Track(s): 20

Dynamical systems and mathematical modelling in OR

Katsunori Ano
Shibaura Institute of Technology
kano2@mac.com

Selma Belen
Ankara
akademik.sb.matematik@gmail.com

Gerhard-Wilhelm Weber
Middle East Technical University
gweber@metu.edu.tr

Track(s): 8

EJOR special session

Roman Slowinski
Poznan University of Technology
roman.slowinski@cs.put.poznan.pl

Track(s): 12

Energy economics, environmental management and multicriteria decision making

Peter Letmathe
RWTH Aachen University
Peter.Letmathe@rwth-aachen.de

Gerhard-Wilhelm Weber
Middle East Technical University
gweber@metu.edu.tr

Track(s): 31

Equilibrium problems in energy

Steven Gabriel
University of Maryland
sgabriel@umd.edu

Track(s): 26

European working group: Data science meets optimization

Patrick De Causmaecker
Katholieke Universiteit Leuven
Patrick.DeCausmaecker@kuleuven.be

Track(s): 1

Expert judgement elicitation

Alec Morton
University of Strathclyde
alec.morton@strath.ac.uk

Track(s): 7

Financial and commodities modeling

Rita D'Ecclesia
Sapienza University of Rome
rita.decclesia@uniroma1.it

Track(s): 5

Financial mathematics and OR

Katsunori Ano
Shibaura Institute of Technology
kano2@mac.com

A. Sevtap Selcuk Kestel
Middle East Technical University
skestel@metu.edu.tr

Gerhard-Wilhelm Weber
Middle East Technical University
gweber@metu.edu.tr

Track(s): 12

Financial mathematics with applications in energy, environment and climate

Katsunori Ano
Shibaura Institute of Technology
kano2@mac.com

Gerhard-Wilhelm Weber
Middle East Technical University
gweber@metu.edu.tr

Track(s): 24

Game theory and operations management

Greys Sosic
University of Southern California
sosic@marshall.usc.edu

Track(s): 16

Game theory, discrete mathematics and their applications

Katsunori Ano
Shibaura Institute of Technology
kano2@mac.com

Track(s): 18

Graphs, telecommunication, networks (contributed)

Fabio D Andreagiovanni
CNRS, Sorbonne University - UTC
d.andreagiovanni@hds.utc.fr

Stanko Dimitrov
University of Waterloo
sdimitro@uwaterloo.ca

Bernard Fortz
Université Libre de Bruxelles
bernard.fortz@ulb.ac.be

Ivana Ljubic
ESSEC Business School of Paris
ivana.ljubic@essec.edu

Dimitri Papadimitriou
Bell Labs - Nokia
dimitri.papadimitriou@nokia-bell-labs.com

Bernard Ries
Université de Fribourg
bernard.ries@unifr.ch

Track(s): 15

Health care management

John Blake
Dalhousie University
john.blake@dal.ca

Michael Carter
University of Toronto
carter@mie.utoronto.ca

Elena Tanfani
University of Genova
etanfani@economia.unige.it

Peter Vanberkel
Dalhousie University
peter.vanberkel@dal.ca

Track(s): 30

Healthcare and knowledge analytics

A. D. Amar
Seton Hall University
amaramar@shu.edu

Genadijs Zaleskis
Riga Technical University
genadijs.zaleskis@rtu.lv

Track(s): 4

Healthcare services

Roberto Aringhieri
University of Torino
roberto.aringhieri@unito.it
Track(s): 25

Humanitarian logistics

Luk Van Wassenhove
INSEAD
luk.van-wassenhove@insead.edu
Track(s): 6

Hyperheuristics

Andrew J. Parkes
University of Nottingham
ajp@cs.nott.ac.uk
Track(s): 11

IFORS sessions

Michael Trick
Carnegie Mellon University
trick@cmu.edu
Track(s): 9

Initiatives for OR education

Kseniia Ilchenko
PhD
kseniia.ilchenko@gmail.com

Olga Nazarenko
National Technical University of Ukraine "Kyiv Polytechnic Institute"
olga.nazarenko@ukr.net

Liudmyla Pavlenko
Ntuu Kpi
l.s.pavlenko@gmail.com

Gerhard-Wilhelm Weber
Middle East Technical University
gweber@metu.edu.tr
Track(s): 31

Inverse optimization

Daria Terekhov
Concordia University
daria.terekhov@concordia.ca
Track(s): 7

Keynote sessions

Track(s): 3

Knowledge as a nation development strategy

A. D. Amar
Seton Hall University
amaramar@shu.edu
Track(s): 25

Location

Sibel A. Alumur
University of Waterloo
sibel.alumur@uwaterloo.ca

Sergio García Quiles
University of Edinburgh
sergio.garcia-quiles@ed.ac.uk

Jörg Kalcsics
University of Edinburgh
joerg.kalcsics@ed.ac.uk

Olivier Peton
Ecole des Mines de Nantes, IRCCyN UMR CNRS 6597
olivier.peton@mines-nantes.fr
Track(s): 10

Location, logistics, transportation, traffic (contributed)

Track(s): 4 18

Long term planning in energy, environment and climate

Nadia Maïzi
MINES ParisTech
nadia.maizi@mines-paristech.fr
Track(s): 29

Lot-sizing and related topics

Bernardo Almada-Lobo
INESC-TEC, Faculty of Engineering of Porto University
almada.lobo@fe.up.pt

Christian Almeder
European University Viadrina
Almeder@europa-uni.de

Stéphane Dauzere-Peres
Ecole des Mines de Saint-Etienne - LIMOS
dauzere-peres@emse.fr

Raf Jans
HEC Montreal
raf.jans@hec.ca
Track(s): 19

Managing risk in supply chains

Iris Heckmann
FZI Research Center for Information Technology
heckmann@fzi.de
Track(s): 15

Mathematical economics

Anna Rubinchik
University of Haifa
arubinchik@econ.haifa.ac.il
Track(s): 5

Matheuristics

Track(s): 13

Metaheuristics - Matheuristics

Marc Sevaux
Université de Bretagne Sud
marc.sevaux@univ-ubs.fr
Track(s): 2 14

Military, defense and security applications

Greg Parlier
Colonel, US Army Retired
gparlier@knology.net

René Séguin
Defence Research and Development Canada
rene.seguin@drdc-rddc.gc.ca
Track(s): 29

Modeling and simulation of supply chains

John Fowler
Arizona State University
john.fowler@asu.edu

Scott Mason
Clemson University
mason@clemson.edu

Track(s): 23

Multicriteria decision analysis

Valentina Ferretti
London School of Economics and Political Science
V.Ferretti@lse.ac.uk

Track(s): 14

Multiobjective optimization

Gabriele Eichfelder
Technische Universität Ilmenau
Gabriele.Eichfelder@tu-ilmenau.de

Akhtar Khan
Rochester Institute of Technology
aaksma@rit.edu

Track(s): 18

Multiobjective optimization methods and applications

Kaisa Miettinen
University of Jyväskyla
kaisa.miettinen@jyu.fi

Track(s): 10

Multiple classifier systems and applications

Koen W. De Bock
Audencia Business School
kdebock@audencia.com

Sureyya Ozogur-Akyuz
Bahcesehir University
sureyya.akyuz@eng.bau.edu.tr

Track(s): 5

Multiple criteria decision analysis

Chin-Tsai Lin
Ming Chuan University
ctlin@mail.mcu.edu.tw

Track(s): 21 23

Multiple criteria decision making and optimization (contributed)

Track(s): 12

Nonlinear optimization with uncertainties

Natasa Krejic
University of Novi Sad Faculty of Science
natasak@uns.ac.rs

Track(s): 17

NSERC/CRSNG special session

Track(s): 6

Operational research in financial and management accounting

Matthias Amen
Bielefeld University
Matthias.Amen@uni-bielefeld.de

Track(s): 2

Operations finance interface

Anne Lange
Technische Universität Darmstadt
a.lange@bwl.tu-darmstadt.de

Track(s): 16

Optimal control applications

Gernot Tragler
Vienna University of Technology
gernot.tragler@tuwien.ac.at

Track(s): 16

Optimization for public transport

Marie Schmidt
Erasmus University Rotterdam
schmidt2@rsm.nl

Anita Schöbel
University Goettingen
schoebel@math.uni-goettingen.de

Track(s): 23

Optimization in renewable energy systems

Serap Ulusam Seckiner
University of Gaziantep
seckiner@gantep.edu.tr

Gerhard-Wilhelm Weber
Middle East Technical University
gweber@metu.edu.tr

Track(s): 27

Optimization of gas networks

Lars Schewe
FAU Erlangen-Nürnberg, Discrete Optimization
lars.schewe@fau.de

Track(s): 20

Optimization, analytics and game theory for health and life sciences

Elena Gubar
Saint-Petersburg State University
alyona.gubar@gmail.com

Gerhard-Wilhelm Weber
Middle East Technical University
gweber@metu.edu.tr

Track(s): 25

OR and ethics

Pierre Kunsch
Vrije Universiteit Brussel
pkunsch@vub.ac.be

Gerhard-Wilhelm Weber
Middle East Technical University
gweber@metu.edu.tr

Track(s): 25

OR for development and developing countries

Subhash Datta
Centre for Inclusive Growth and Sustainable Development
subhash.datta@gmail.com

Elise del Rosario
OSSFFI
elise@jgdelrosario.com

Sue Merchant
Blue Link Consulting
suemerchant@hotmail.com

Gerhard-Wilhelm Weber
Middle East Technical University
gweber@metu.edu.tr

Leroy White
University of Warwick
Leroy.White@wbs.ac.uk

Track(s): 25

OR in agriculture

Concepcion Maroto
Universitat Politecnica de Valencia
cmaroto@eio.upv.es

Track(s): 26

OR in forestry

Mikael Rönnqvist
Département de génie mécanique
mikael.ronnqvist@gmc.ulaval.ca

Track(s): 30

OR in healthcare

Joana Matos Dias
Inesc Coimbra
joana@fe.uc.pt

Ana Viana
Inesc Tec/isep
aviana@inescporto.pt

Track(s): 28

OR in industry, software for OR (contributed)

Track(s): 31

OR in mining

Roussos Dimitrakopoulos
McGill University
roussos.dimitrakopoulos@mcgill.ca

Doreen Thomas
University of Melbourne
doreen.thomas@unimelb.edu.au

Track(s): 27

OR in sports

James Cochran
Louisiana Tech University
jcochran@cab.latech.edu

Dries Goossens
Ghent University
Dries.Goossens@ugent.be

Track(s): 26 31

OR in the oil and gas sectors

Ignacio Grossmann
Carnegie Mellon University
grossmann@cmu.edu

Track(s): 28 29

Plenary sessions

Track(s): 3

Port operations

Claudia Caballini
University of Genova
claudia.caballini@unige.it

Evrim Ursavas
University of Groningen
e.ursavas@rug.nl

Track(s): 21

Probabilistc methods and simulation in health and life sciences

Katsunori Ano
Shibaura Institute of Technology
kano2@mac.com

Gerhard-Wilhelm Weber
Middle East Technical University
gweber@metu.edu.tr

Track(s): 26

Problem structuring interventions

Leroy White
University of Warwick
Leroy.White@wbs.ac.uk

Track(s): 6

Production management, supply chain management (contributed)

Track(s): 10

Recent advances in performance and efficiency evaluation

Adel Hatamimarbini
Université de Liège
adel.hatamimarbini@ulg.ac.be

Track(s): 13

Revenue management and pricing

Track(s): 8

Revenue management, pricing, managerial accounting (contributed)

Track(s): 11

Riemannian optimization and related topics

Orizon P Ferreira
Universidade Federal de Goiás
orizon@ufg.br

Track(s): 19

Robust optimization

Mustafa Pinar
Bilkent University
mustafap@bilkent.edu.tr

Track(s): 19

Scheduling in job shops, flow shops, and healthcare

Frank Werner
Otto-von-Guericke University, FMA,I
frank.werner@mathematik.uni-magdeburg.de

Track(s): 4

Scheduling problems in logistics

Dominik Kress
University of Siegen
dominik.kress@uni-siegen.de

Erwin Pesch
University of Siegen
erwin.pesch@uni-siegen.de

Track(s): 13

Scheduling: Theory and applications

Debora Ronconi
University of Sao Paulo
dronconi@usp.br

Track(s): 20 26

Simulation

David Krahl
Kromite, LLC
dkrahl@kromite.com

Matt Gorman
Kromite, LLC
mgorman@kromite.com

Andrew Collins
Old Dominion University
dr.a.collins@gmail.com

Patrick Hester
Old Dominion University
PTHester@odu.edu

Track(s): 21

Simulation in management accounting and control

Stephan Leitner
Alpen-Adria-Universität Klagenfurt
stephan.leitner@aau.at

Friederike Wall
Alpen-Adria-Universitaet Klagenfurt
friederike.wall@uni-klu.ac.at

Track(s): 9

Simulation, stochastic programming and modeling (contributed)

Track(s): 22

Sports analytics

Donald Hearn
Univ of Florida
donaldhearn@yahoo.com

Track(s): 12

Stochastic assessment of renewable energy

John Boland
University of South Australia
john.boland@unisa.edu.au

Track(s): 26

Stochastic modeling and simulation in engineering, management and science

Katsunori Ano
Shibaura Institute of Technology
kano2@mac.com

Erik Kropat
Universität der Bundeswehr München
erik.kropat@gmx.de

Zeev (Vladimir) Volkovich
Ort Braude Academic College
zeev@actcom.co.il

Gerhard-Wilhelm Weber
Middle East Technical University
gweber@metu.edu.tr

Track(s): 5

Stochastic optimization

Juliana Nascimento
Princeton University
jnascime@princeton.edu

Warren Powell
Princeton University
powell@princeton.edu

Track(s): 20

Supply chain management

Moritz Fleischmann
University of Mannheim
Moritz.Fleischmann@bwl.uni-mannheim.de

Herbert Meyr
University of Hohenheim
H.Meyr@uni-hohenheim.de

Track(s): 11

Sustainable living: Cognitive, social, economical, ecological and world view

Sadia Samar Ali
New Delhi Institute of Management , New Delhi , India
sadiasamarali@gmail.com

Pedamallu Chandra Sekhar
Dana-Farber Cancer Institute
pcs.murali@gmail.com

Ulrike Reisach
Neu-Ulm University of Applied Sciences
ulrike.reisach@hs-neu-ulm.de

Gerhard-Wilhelm Weber
Middle East Technical University
gweber@metu.edu.tr

Track(s): 30

Sustainable logistics

Maximilian Schiffer
RWTH Aachen University
maximilian.schiffer@om.rwth-aachen.de

Michael Schneider
RWTH Aachen
schneider@dpor.rwth-aachen.de

Track(s): 14

Teaching OR

Maria Antónia Carravilla
Universidade do Porto | Faculdade de Engenharia
mac@fe.up.pt

José Fernando Oliveira
University of Porto, Faculty of Engineering
jfo@fe.up.pt

Track(s): 31

Technical and financial aspects of energy problems

Univ. Ass. Dr. Raimund Kovacevic
Institut für Stochastik und Wirtschaftsmathematik, ORCOS
raimund.kovacevic@tuwien.ac.at

Track(s): 29

Telecommunications and network optimization

Fabio D Andreagiovanni
CNRS, Sorbonne University - UTC
d.andreagiovanni@hds.utc.fr

Stanko Dimitrov
University of Waterloo
sdimitro@uwaterloo.ca

Bernard Fortz
Université Libre de Bruxelles
bernard.fortz@ulb.ac.be

Ivana Ljubic
ESSEC Business School of Paris
ivana.ljubic@essec.edu

Dimitri Papadimitriou
Bell Labs - Nokia
dimitri.papadimitriou@nokia-bell-labs.com

Track(s): 1 11

Timetabling and project management

Dominik Kress
University of Siegen
dominik.kress@uni-siegen.de

Erwin Pesch
University of Siegen
erwin.pesch@uni-siegen.de

Track(s): 12

Traffic flow theory and control

Nicolas Chiabaut
Université de Lyon, ENTPE / IFSTTAR
nicolas.chiabaut@entpe.fr

Nikolas Geroliminis
EPFL
nikolas.geroliminis@epfl.ch

Mohsen Ramezani
University of Sydney
mohsen.ramezani@sydney.edu.au

Track(s): 11

Vehicle routing

Roberto Roberti
VU University Amsterdam
r.roberti@vu.nl

Daniele Vigo
University of Bologna
daniele.vigo@unibo.it

Track(s): 7

Session Chair Index

Author Index

Session Index

Monday, 8:30-10:00

Monday, 10:30-12:00

Monday, 13:30-14:30

Monday, 15:00-16:30

Monday, 16:45-18:15

Tuesday, 8:30-10:00

Tuesday, 10:30-12:00

Tuesday, 13:30-14:30

Tuesday, 15:00-16:30

Tuesday, 16:45-18:15

Wednesday, 8:30-10:00

Wednesday, 10:30-11:30

Thursday, 8:30-10:00

Thursday, 10:30-12:00

Thursday, 13:30-14:30

Thursday, 15:00-16:30

Thursday, 16:45-18:15

Friday, 8:30-10:00

Friday, 10:30-12:00