Tuesday, 14:30-16:00

■ UA-09

Tuesday, 14:30-16:00 - Room: H15

Hexaly Workshop

Stream: PC Stream
Workshop session
Chair: *Léa Blaise*

1 - Modeling and Solving Packing Problems with Hexaly Studio
Léa Blaise, Bienvenu Bambi, Michael Feldmeier, Leona Gottwald

Hexaly Optimizer is a global mathematical solver that integrates both exact and heuristic techniques to tackle complex optimization problems. At its core is an innovative modeling formalism based on nonlinear and set-oriented expressions, enabling users to write compact, expressive models for a wide variety of optimization problems. This formalism not only simplifies the modeling process but also provides the solver with higher-level structural information, allowing it to leverage advanced algorithmic techniques from the literature to obtain state-of-the-art performance on classic optimization domains such as routing, scheduling, and packing.

In this hands-on workshop, we will focus on the application of Hexaly to packing problems, showcasing how the solver's set-based modeling capabilities naturally align with the structure of these problems. Participants will be guided through building and solving real-world packing problems using Hexaly Studio, a web-based integrated development environment designed specifically for optimization modeling. Hexaly Studio features intuitive dashboards, interactive widgets, and graphical solution visualizations, making it easy to both formulate models and interpret results. Through guided examples and interactive problem-solving, participants will gain hands-on experience with Hexaly and will be equipped to explore it further in their own research or applied projects.

— If you are planning to attend the workshop, please write to contact@hexaly.com.

■ UA-10

Tuesday, 14:30-16:00 - Room: H16

Funding opportunities for Young Researchers: Programs and experiences

Stream: Dokt!OR
Panel session
Chair: *Michael Römer*

1 - Funding opportunities for Young Researchers: Programs and experiences
Uta Mohring, Marlin Wolf Ulmer

For young researchers aspiring to pursue an academic career, there are several funding opportunities helping to gain international experience, acquire funding for one's own position and to establish a junior research group. In this session, a representative from the German Research Foundation (DFG) will give an overview of some relevant programs. Afterwards, we have a panel discussion where successful recipients of funds and grants share their insights and experiences. The panellists are:

Dr. Uta Mohring, Eindhoven University of Technology Postdoctoral Fellowship (University of Toronto), Walter Benjamin Postdoctoral Fellowship (DFG)

J-Prof. Dr. Michael Schaub, RWTH Aachen Marie Skłodowska Curie Postdoctoral Fellowship (EU), NRW Return Programme, ERC Starting Grant (EU)

Prof. Dr. Marlin Ulmer, OVGU Magdeburg Emmy Noether Programme (DFG), Individual Research Grants (DFG)

Tuesday, 16:30-18:00

■ UB-09

Tuesday, 16:30-18:00 - Room: H15

GAMSPy Workshop

Stream: PC Stream
Workshop session
Chair: *Frederik Fiand*
Chair: *Lutz Westermann*

1 - An Introduction to Modelling with GAMSPy
Frederik Fiand, Lutz Westermann

This 90-minute workshop offers a hands-on introduction to GAMSPy. GAMSPy combines the high-performance GAMS execution system with the flexible Python language, creating a powerful mathematical optimization package. It acts as a bridge between the expressive Python language and the robust GAMS system, allowing you to create complex mathematical models effortlessly.

Join us to explore GAMSPy's fundamental functionalities through practical, interactive exercises. We'll cover everything from defining sets, parameters, variables, and equations to solving models and retrieving results, all within a familiar Python environment. Beyond the basics, we'll also provide a glimpse into more advanced features, demonstrating how GAMSPy can streamline complex modeling workflows and enhance your analytical capabilities.

Whether you're a seasoned GAMS user looking to integrate with Python or a Python user curious about optimization, this workshop will equip you with the essential skills to get started with GAMSPy. — If you would like to participate in the workshop, please send an e-mail with the subject "GAMSPy Workshop - OR 2025" to or2025@gams.com.

■ UB-10

Tuesday, 16:30-18:00 - Room: H16

ORntrepreurship

Stream: Dokt!OR
Panel session
Chair: *Michael Römer*
Chair: *Sabrina Backs*

1 - ORntrepreurship
Geoffrey De Smet, Jens Peter Kempkes, Gerald Lach

A PhD in OR can be a great starting point for entrepreneurial activities. The following four panellists each started successful companies making use of their skills and experiences from conducting academic research projects in OR, and they are happy to share their stories and their lessons learned:

Geoffrey De Smet, CTO and Co-Founder, timefold, https://timefold.ai/

Dustin Feld,Managing Director and Co-Founder, adiutaByte, https://adiutabyte.de/

Jens Peter Kempkes, Managing Director and Co-Founder, OPTANO, https://optano.com

Gerald Lach, Managing Director and Co-Founder, mathPlan, https://mathplan.de/

Wednesday, 8:45-10:15

■ WA-01

Wednesday, 8:45-10:15 - Room: Audimax

Opening Ceremony & GOR Scientific Award

Stream: PC Stream
Plenary session
Chair: *Matthias Amen*

Wednesday, 10:45-12:15

■ WB-01

Wednesday, 10:45-12:15 - Room: Audimax

Ridepooling

Stream: Mobility, Transportation, and Traffic
Invited session
Chair: *Kendra Reiter*

1 - Strategic Planning of Ridepooling Services
Lena Dittrich, Anita Schöbel, Sarah Roth

Demand responsive ridepooling services can be a useful addition or expansion for line based public transport systems. As such, they are becoming more and more common. The operational aspect of dial-a-ride services is a well researched problem, both in an offline and an online setting. Dial-a-ride problems typically aim to assign passenger requests to the ridepooling vehicles and determine their routes through an underlying road network, thereby minimizing travel time and costs for the provider. In this talk, we consider ridepooling from a strategic perspective, disregarding operational details. Strategic decisions include in which areas ridepooling should be offered and how many vehicles are needed such that the demand can be served.

We present models for strategic ridepooling that work in a similar way as models for line planning. We analyze the main differences between traditional line based and demand responsive public transport. We then turn to the integrated planning of ridepooling services and traditional line based public transport such as busses or trains. For a given customer demand in a transport network, these models decide which type of transportation is more suitable in which area of the network, such that all passengers can be transported either by regular lines or by ridepooling, while keeping the overall cost minimal.

2 - Arrival Commitments in Traveling Salesman Problems with Stochastic Demand
Lina Schmidt, Julian Golak, Arne Schulz, Malte Fliedner

In ridepooling services, customers can typically choose from a menu of trips which can differ in arrival time commitments (and/or prices). The arrival time commitment will typically have a strong effect on whether customers request a particular trip or not. An unambitious arrival time commitment may deter customers, leading to a higher chance that they will reject the offer which can result in an underutilization of resources. Conversely, offering a more ambitious arrival commitment increases the probability that customers will request this trip. Since the service provider seeks to fulfil its commitment, this may lead to an increased rejection of requests by the service provider and thus a loss in revenue. This work investigates the interdependency between the arrival commitments and the customer demand within a simplified traveling salesman setting where all customers are transported by a single shuttle to a common destination. We model the customer acceptance as the probability depending on the offered arrival time. We develop a formal representation of this two-stage stochastic optimization problem and introduce both exact and heuristic algorithmic approaches for deriving (near) optimal arrival time commitments.

3 - Optimising Dial-a-Ride Services with Public Transportation Integration Using an Event-Based Formulation
Lorenz Alexander Saathoff, Arne Schulz

Demand-responsive transport services have become more popular in recent years. The Integrated Dial-a-Ride Problem (I-DARP) describes the optimisation problem of determining vehicle routes serving customers in an area around a station while respecting their desired connection to timetable-based public transport. Passengers are allowed to request a ride either from or to the station. Conventionally, the DARP is modelled using time-space formulations which represent the customer locations as nodes. However, recently, the focus has shifted towards event-based approaches, representing the DARP as a sequence of events, thus enhancing computational performance. Following this line of research, an event-based formulation for the public transport-integrated Dial-a-Ride problem is proposed. This formulation captures the problem's unique properties, including many-to-one routing and coincident requested arrival/departure times at the public transport stop due to the embedded timetable. By explicitly modelling the boarding and alighting events, numerous restrictions pertaining to vehicle capacity, request pairing, and precedence constraints are adhered to in the construction of the event graph. A mixed-integer program for finding optimal routes is proposed and solved for two objectives: (1) minimise passenger inconvenience in terms of waiting time and (2) minimise total distance travelled by the vehicles. The results are compared and managerial implications are derived and discussed. The computational experiments on realistic instances are also used to evaluate the performance of the event-based formulation for the I-DARP.

4 - Branch-and-Price for the line-based Dial-a-Ride Problem without Time Windows
Kendra Reiter, Marie Schmidt, Michael Stiglmayr

The Dial-a-Ride Problem (DARP) is a well-studied optimization problem, concerned with transporting a set of passenger requests, each with an origin, a destination, a load, and time windows denoting the earliest departure or latest arrival. As the DARP is NP-hard, pre-processing steps that eliminate infeasible connections based on tightened time windows are essential for the success of most MILP-based solution methods.

In the line-based Dial-a-Ride Problem (liDARP), we consider a set of bus stations connected by a line, i.e., with a pre-defined ordering, a set of vehicles, and requests traveling between stations. The vehicles may take shortcuts, wait at stations, and turn when empty. Our objective is to balance the environmental benefits (by pooling passengers and reducing driven kilometers), with the service effectiveness measured by the number of passengers transported.

In rural areas, where demand is sparse and travel distances are longer, strict time windows and maximum ride time constraints leave little flexibility to pool requests, reducing the environmental benefits. We consider a liDARP variant without time windows. While this relaxation promises higher pooling rates, it also renders many common solution methods, which use pre-processing steps dependent on tight time windows, ineffective, requiring new algorithmic approaches with competitive running times. Future work may build upon this variant, using the proposed procedures to consider instances with realistic (non-tight) time windows.

Leveraging the underlying line structure, we introduce subroutes, which are tuples encoding the serviced stations between turns. Using subroutes and alternating the driving direction, we develop a Branch-and-Price framework to solve the liDARP without time windows.

■ WB-02

Wednesday, 10:45-12:15 - Room: H4

Robust Optimization

Stream: Discrete and Combinatorial Optimization
Invited session
Chair: *Michael Hartisch*

1 - Fast scenario addition for two-stage robust mixed-integer programs
Johannes Kager, Marc Goerigk, Dorothee Henke, Fabian Schäfer, Clemens Thielen

We consider two-stage robust mixed-integer programs with finite uncertainty sets and present a new approximate scenario addition method to efficiently solve such problems. Our method builds upon the classical scenario-addition framework and introduces several enhancements aimed at improving scalability, particularly when the second-stage problems are computationally demanding. Key features include the use of dual bounds for second-stage problems to accelerate the identification of promising scenarios to be added to the master problem and adaptive time limits to prevent stagnation on particularly hard second-stage problems. Gaps are propagated between master problem and second-stage problems to enable earlier termination in cases where only a non-zero optimality gap is to be reached.

We evaluate our method on two application problems: a robust capacitated location routing problem and a robust integrated berth allocation and quay crane assignment and scheduling problem. The first problem features a particularly hard second stage, whereas the second problem features an easier second stage and is used to show the general applicability of our method. Our results demonstrate significant performance improvements over existing scenario addition methods in terms of solvable instance size and time efficiency, highlighting the potential of the proposed algorithm for handling large instance sizes.

We also given an outlook on a possible extension of the method to bi-objective two-stage robust problems.

2 - Approximating Robust Problems by Uncertainty Sets
Marc Goerigk, André Chassein, Jamie Fairbrother

For robust combinatorial optimization, a central problem ingredient that decides the problem complexity is the type of uncertainty set. Previous research has already discovered modifications to the uncertainty set as a path to derive approximation results by replacing high-cardinality discrete uncertainty sets by low-cardinality sets. In this talk, I discuss possibilities to replace one type of uncertainty set by another type of uncertainty set, including computational challenges of this approach.

3 - Scenario reduction for distributionally robust optimization
Kevin-Martin Aigner, Sebastian Denzler, Frauke Liers, Sebastian Pokutta, Kartikey Sharma

Stochastic and (distributionally) robust optimization problems often become computationally challenging as the number of scenarios increases. Scenario reduction is therefore a key technique for improving tractability. We introduce a general scenario reduction method for distributionally robust optimization (DRO), which includes stochastic and robust optimization as special cases. Our approach constructs the reduced DRO problem by projecting the original ambiguity set onto a reduced set of scenarios. Under mild conditions, we establish bounds on the relative quality of the reduction. The methodology is applicable to random variables following either discrete or continuous probability distributions, with representative scenarios appropriately selected in both cases. Given the relevance of optimization problems with linear and quadratic objectives, we further refine our approach for these settings. Finally, we demonstrate its effectiveness through numerical experiments on mixed-integer benchmark instances from MIPLIB and portfolio optimization problems. Our results show that the proposed approximation significantly reduces solution time while maintaining high solution quality with only minor errors.

4 - An Expansion-Based Approach for Multistage Robust Discrete Linear Programs
Michael Hartisch

In robust optimization, decision makers hedge against uncertainty by optimizing over worst-case scenarios—yet general-purpose frameworks for problems with more than two decision stages remain scarce. We introduce an expansion-based solver for multistage robust discrete linear programs. Leveraging the semantics of Quantified Integer Programming (QIP)—which extends Quantified Boolean Formulas with integer variables and linear constraints—we employ Counterexample-Guided Abstraction Refinement (CEGAR) on the scenario tree to resolve the underlying feasibility subproblems, iteratively refining only those branches that are crucial. To solve optimization problems, this is wrapped in a binary-search scheme over a linear objective function. Our solver outperforms existing search-based QIP methods on certain benchmarks and even delivers performance gains over leading expansion-based QBF solvers on specific instances.

■ WB-03

Wednesday, 10:45-12:15 - Room: H5

Uncertainty and energy

Stream: Energy and Sustainability
Invited session
Chair: *Dominik Möst*

1 - Rethinking N-1 Security: Balancing Reliability and Economy in Electricity Transmission
Akshay Singh Yadav, Hannes Hobbie

The German power grid's shift toward renewables poses major operational challenges, notably in congestion management and grid security. Variability in generation and regional imbalances have driven congestion volumes up by over 60% in recent years. Ensuring N-1 security further raises costs, as transmission capacity must be reserved for potential line outages. In particular, preserving N-1 security for individual contingencies can become disproportionately expensive under specific demand and feed-in patterns. This motivates a chance-constrained framework that selectively relaxes the N-1 criterion in such events for single contingencies, enabling more efficient use of transmission capacity while maintaining an acceptable balance between reliability and cost. We extend the ELMOD framework, a well-established tool for modelling electricity markets and congestion management in the German grid, by integrating a mixed-integer program to optimize the N-1 security relaxation. This enables strategic switching between contingency and normal operating flows for specific lines and hours. The models aim to minimize congestion management costs for pre-defined reliability values representing different N-1 security levels. Results demonstrate that selective N-1 relaxation can yield annual and single-day congestion cost reductions up to 26-30%. Two strategies—cumulative time-based and individual line-based relaxations—are compared, revealing that fine-grained, line-specific relaxations offer greater savings with manageable security trade-offs. Our study offers a novel, system-theoretic approach to integrating risk-based security assessment into grid operation planning, serving as a first step toward more flexible, sustainable, and cost-efficient system management.

2 - On the effects of unexpected extreme events in an ex-post analysis of integrated energy system planning

Richard Schmitz, Felix Frischmuth, Magnus Korpås, Philipp Härtel

The required pace of energy system transformation involves significant uncertainties and complexities. Furthermore, the rising frequency of extreme events, coupled with ongoing climate change, underscores the urgent need to enhance the resilience of energy systems. These extreme events encompass natural phenomena such as earthquakes and severe weather, as well as human-induced incidents such as wars, terrorism, and accidents. The aim of this paper is to show the influence of selected extreme events on the cost-optimised planning of integrated energy systems. For this purpose, we use EMPRISE, a multi-stage stochastic linear programming framework for modelling and optimising integrated energy system planning. First, investment and operational planning is conducted for the energy system transformation pathway leading to 2045, serving as a regular reference scenario. This analysis may incorporate various meteorological years as uncertainties. Second, the expanded capacities of power plants (such as gas turbines, solar photovoltaics, and onshore/offshore wind power), storage technologies (e.g. batteries), and consumer technologies (including electrolysers and heat pumps) are then utilised in a subsequent dispatch calculation influenced by unexpected extreme events. Our approach allows for an ex-post impact analysis of the amount and frequency of uncovered loads in the system and identifies the recourse options chosen by the model when additional capacity expansion is not permitted. The results aim to illustrate the essential shift from deterministic optimisation with subsequent parameter sensitivities to stochastic optimisation including extreme events, also referred to as resilient planning, in energy system modelling.

3 - Hybrid Stacked-Ensemble and LLM-Augmented Framework for Predictive Maintenance of Wind Turbines

Mohamed Saâd El Harrab, Quoc-Tuan Tran

Modern wind turbines generate dense SCADA and vibration logs in which early fault signals are easily masked by noise. We introduce a hybrid framework that pairs a stacked ensemble of anomaly-detection models with a large language model (LLM). Cleaned, windowed sensor data are processed by complementary detectors (Isolation Forest, ν-SVM, Prophet residual analysis and a convolutional auto-encoder...). Their calibrated scores feed a sparsity-regularised logistic combiner that minimises a cost-weighted sum of false and missed alarms. A Kolmogorov-Smirnov guard monitors distribution drift and triggers lightweight retraining as conditions evolve.

The LLM enlarges the feature space with automatically generated descriptors and periodically adjusts detector weights using compact context vectors such as season and wind speed. Operator feedback is distilled into concise rules that mute recurring false alerts, closing the loop. Tests on multi-year fleet records improve precision-recall while halving unnecessary alarms, demonstrating a scalable and interpretable tool for turbine-health management.

■ WB-04

Wednesday, 10:45-12:15 - Room: H6

Network Optimization

Stream: Discrete and Combinatorial Optimization
Invited session
Chair: *Arie Koster*

1 - On Solving the Stochastic Steiner Tree Problem with a Fast Heuristic

Berend Markhorst, Alessandro Zocca, Joost Berkhout, Rob van der Mei

The Stochastic Steiner Tree Problem (SSTP) is well-known in the literature and has many applications. Although there are a few approaches specifically tailored to this stochastic optimization problem, there are considerably more state-of-the-art heuristics for its deterministic equivalent, the Steiner Tree Problem (STP). In this work, we show how to use one of these STP heuristics in a novel framework to solve the SSTP. This approach is a powerful, yet simple and easy-to-implement way of solving this complex problem. We test our method with benchmark instances from the literature and the numerical results show considerably faster computation times compared to the current state-of-the-art, with an optimality loss of approximately 5%.

2 - Analyzing Subtour Elimination Strategies for the Travelling Salesman Problem using Branch-and-Cut

Tobias Klein, Kathrin Fischer

The Travelling Salesman Problem (TSP) is an NP-hard optimization problem that seeks a minimum-cost Hamiltonian cycle over a set of nodes. In this work, the TSP is solved exactly by first relaxing both the integrality and subtour elimination constraints of its MILP formulation. This relaxation may result in a disconnected tour or a non-integer solution, rendering it infeasible for the TSP. To ensure feasibility, the Branch-and-Cut method is employed in this work, incorporating separation algorithms to detect violated subtour constraints. These separation algorithms are applied at every node in the branch-and-bound tree that is not yet fathomed, ensuring that the feasible region is incrementally refined until an optimal solution is achieved. A key research gap in this process is determining the optimal number and selection strategy for violated subtour constraints to reintroduce at each iteration. The larger the number of constraints, the more restricted the solution space becomes, potentially increasing computational complexity due to the enlarged problem size, whereas a smaller number of constraints may slow down convergence. It is, therefore, crucial to optimize constraint addition for efficiency. In this study, several strategies for adding subtour elimination constraints are implemented and evaluated using the Gurobi solver and the TSPLIB. The performance of these strategies is evaluated in terms of solution time and simplex iterations. The results obtained from this study offer insights into the effects of different strategies on the Branch-and-Cut algorithm's performance, contributing to enhanced efficiency in solving the TSP and similar routing problems.

3 - Comparing Branching Rules for the Quota Steiner Tree Problem with Interference

Jaap Pedersen, Niels Lindner, Daniel Rehfeldt, Thorsten Koch

Branching decisions play a crucial role in branch-and-bound algorithms for solving combinatorial optimization problems. In this talk, we investigate several branching rules applied to the Quota Steiner Tree Problem with Interference (QSTPI). The original Quota Steiner Tree Problem (QSTP) generalizes the classical Steiner Tree Problem (STP) in graphs by seeking a minimum-cost tree that connects a subset of profit-associated vertices to meet a given quota. The extended version, QSTPI, introduces interference among vertices - selecting certain vertices together reduces their individual contributions to the overall profit. This problem arises, for example, in positioning and connecting wind turbines, where turbines possibly shadow other turbines, reducing their energy yield. While exact solvers for standard STP-related problems often rely heavily on reduction techniques and cutting-plane methods - rarely generating large branch-and-bound trees - experiments reveal that large instances of QSTPI require significantly more branching to prove optimality. In contrast to branching on variables, we utilize the combinatorial structure of the QSTPI by branching on the graph's vertices. We adapt classical and problem-specific branching rules and present a comprehensive computational study comparing the effectiveness of these branching strategies.

4 - Sparse Solutions for Network Optimization Problems

Arie Koster, Pauline Lückemann

A solution is called sparse if there the encoding vector has only few nonzero entries. In many practical applications, sparse solutions have (managerial, operational) benefits that need to be considered in addition to the original objective function. In this presentation, we discuss three fundamental network optimization problems and the impact of sparsity on them: Sparse Shortest Path remains polynomial time solvable, Sparse Maximum Flow and Sparse Minimum Cost Flow become NP-complete in general graphs. For series parallel graphs, we provide polynomial and pseudo-polynomial algorithms for the latter two cases.

■ WB-05

Wednesday, 10:45-12:15 - Room: H7

Behavioral Decision Approaches for Risk & Innovation

Stream: Decision Theory and Multi-criteria Decision Making
Invited session
Chair: *Marcus Wiens*
Chair: *Naiema Shirafkan*

1 - Analysing Stakeholder Interactions in Green Hydrogen Supply Chains through Blockchain Technology

Naiema Shirafkan, Marcus Wiens

The green hydrogen supply chain involves multiple stakeholders whose interactions influence production quality, market trust, and system sustainability. This study examines how blockchain technology can reshape these interactions by enhancing stakeholders' interaction in supply chain system of green hydrogen and addressing consumer concerns about hydrogen purity. Using a game-theoretic model, we compare a conventional supply chain with a blockchain-enabled system, where key players - upstream producers and downstream retailers - make strategic decisions on pricing, quality, and blockchain adoption. Our findings show that blockchain implementation fosters stakeholder trust, leverages pricing strategies, and has the potential to improve overall supply chain efficiency. Furthermore, incentive mechanisms, including tax benefits and manufacturer rewards, encourage blockchain adoption, reinforcing sustainability goals. This research provides a structured analysis of how digital innovations can enhance supply chain procedures and offers strategic insights for policymakers and industry leaders aiming at a transparent and competitive hydrogen economy.

2 - The Impact of Time Pressure on Phishing Email Identification

Ashima Khurana

Cybersecurity involves decision-making under risk and uncertainty within complex, interconnected environments. Attackers exploit this complexity by leveraging human vulnerabilities through social engineering tactics. The current study delves deeper into the factors affecting cybersecurity behaviour amid evolving cyber-threats. Specifically, we examine the role of time pressure and the mediating effect of risk awareness on phishing detection performance. While prior research has primarily focused on user characteristics and source credibility, limited attention has been given to contextual factors that affect information processing, such as time pressure. Drawing on the theoretical foundation of dual process theory, which distinguishes between fast and automatic (System 1) and slow and deliberative (System 2) thinking, this study manipulates time pressure to examine the impact of cognitive processing on phishing detection. Time pressure is hypothesized to hinder System 2 processing by increasing cognitive load, leading to reliance on System 1, which often overlooks minor red flags in emails. This shift may lead to faulty judgments in the high-risk cybersecurity context. In a within-subject role-playing experiment, participants simulate an employee's role and respond to a series of emails, deciding whether to engage with or delete each message. They undergo two treatments: time pressure induced by explicitly limiting the time available to answer an email and no time pressure, followed by a post-questionnaire survey on behavioural and cognitive preferences. The expected results are reduced detection accuracy under time pressure due to reliance on System 1, and improved accuracy in both cognitive modes when primed with an awareness video.

3 - Identification of Future PV Waste Hotspots in Germany: A Monte Carlo-Based Infrastructure Demand Analysis Using Market Data

Moritz Czyrnia, Bastian Gaidzik

The increasing volume of aging photovoltaic (PV) systems in Germany will soon lead to a substantial rise in decommissioned modules requiring sustainable end-of-life management. However, the current infrastructure for PV module collection and recycling remains fragmented and uncoordinated, lacking the spatial and capacity planning needed to handle future volumes. In this study, we develop a spatio-temporal forecasting model by combining national installation data from the German "Marktstammdatenregister" with a Monte Carlo simulation that incorporates uncertainty in system lifetimes, technology types, and degradation rates. The simulation runs multiple scenarios to project PV waste generation until 2050 at district level, capturing regional differences and trends over time. We assess logistical robustness and environmental performance by modeling transport distances, facility capacities, and greenhouse gas emissions associated with waste flows. The expected outcome is the identification of high-priority regions where future recycling infrastructure is most urgently needed. These findings enable evidence-based planning and highlight where investment and policy efforts should be directed to establish an efficient and low-emission recovery system. The analysis should provide a decision-support framework for policymakers, municipalities, and recycling firms aiming to scale PV waste management in line with circular economy principles and national sustainability goals.

4 - Decentralized Hydrogen Supply Chains under Disruption: A Game-Theoretic Perspective on Resilience and Sourcing

Hamed Rajabzadeh, Marcus Wiens

This presentation focuses on the decentralized structure of a dual-sourcing hydrogen supply chain exposed to disruption risk in renewable electricity supply. We model strategic interactions between a hydrogen producer relying on renewable energy and a backup supplier using fossil fuels, with logistics support from a third-party transporter. A game-theoretic framework is used to analyze how the primary company reacts to uncertainty through proactive and reactive sourcing strategies. Key findings reveal that despite economic volatility, the decentralized system exhibits high flexibility and changeability, enabling early responses to disruption. The model also identifies a critical disruption threshold at which the producer shifts from single to dual sourcing, offering managerial insight into supply chain design under uncertainty. This work contributes to understanding how decentralized decision-making can support resilient energy transitions when central coordination is not feasible.

■ WB-06

Wednesday, 10:45-12:15 - Room: H9

Predictive Analytics: Forecast Combination & Hyperparameter Optimization

Stream: Analytics, Data Science, and Forecasting
Invited session
Chair: *Sven F. Crone*

1 - Shifting Forecast Combination Weights Estimated on Subsamples towards Full Sample Weight Determination

Veronika Wachslander

Combining forecasts of different predictive models or forecasters has proven to be powerful for increasing predictive accuracy. Numerous techniques exist to determine the combination weights assigned to the models or forecasters. One common approach estimates optimal weights (OW) by minimizing the mean squared error (MSE) on a provided set of past (training) data. However, the estimated weights are influenced by random structures and tend to overfit limited training data. An approach for reducing this overfitting, while still incorporating differences in predictive ability is to shrink OW towards equal weights (EW). However, this technique typically suffers from structural distortions (i.e., strong overfitting) of the initially learned OW, which cannot be remedied by shrinking unless full shrinkage to EW is applied.

Modern machine learning-based ensemble methods, which estimate parameters (weights in this context) on multiple training subsamples and aggregate the results, are less prone to overfitting compared to estimations on the full training sample.

We introduce a method that aims at learning more robust combination weights by estimating OW on multiple subsamples of training data and shrinking these weights towards EW to obtain an ensemble of decorrelated weight vectors. Subsequently, these vectors are linearly shifted to a controllable degree towards (less overfitted) weights learned on the full training sample. The final combination weights are obtained by averaging the ensemble of shifted weight vectors.

The method is evaluated and compared to OW and EW on synthetic datasets with varying training and subsample sizes, different shrinkage and shifting levels, and different variance-covariance structures of forecasters.

2 - Generating Artificial Training Errors for Forecast Combination Based on Shrunk Sample Covariance Matrices

André Konersmann, Thomas Setzer

In the era of data-driven decision-making, accurate and reliable predictions are crucial for future planning and the organizational success of businesses across various sectors. Forecast combination has proven effective in improving predictive performance over individual forecasting models by leveraging the strengths of multiple forecasters and mitigating the potentially high errors of any single forecaster.

However, learning weights for forecast combination based on past error observations is prone to overfitting and high out-of-sample errors when trained on limited data - a common scenario in many forecasting tasks. This is due to the instability of the sample covariance matrix and its inverse in such settings, which are typically used to compute, for example, in-sample optimal weights.

In this study, we introduce an approach to generate additional synthetic error observations. The aim is to enable the learning of more stable weights on these extended training datasets. Artificial data generation techniques have been shown to reduce sensitivity to random patterns and mitigate overfitting in various domains, yet they have received little attention in the context of forecast combination. We develop and evaluate methods to generate multivariate forecast error data from shrunk sample covariance matrices, aiming to reduce overfitting while preserving the generalizable structure of the original data.

In experimental evaluations using Monte Carlo-simulated forecast error data, we assess whether our proposed methods can reduce overfitting and improve out-of-sample accuracy compared to learning weights solely from the original data.

3 - Utility-Driven Hyperparameter Optimization for Tabular Data GANs via Ranking-and-Selection

Mick Molitor

A plethora of applications can benefit from the use of Generative Adversarial Networks (GANs) to generate samples, from data augmentation to solving complex optimization problems. Yet despite their versatility, GAN training poses a tough, often underreported, optimization challenge. Tabular GANs are notoriously brittle: small changes in weight initialization can significantly affect training and output quality. Traditional hyperparameter optimization (HPO) methods—such as grid search, random search, and Bayesian optimization—typically assume consistent outcomes across runs, often neglecting the substantial role of stochasticity in GAN performance compared to other neural architectures. To better understand the intricacies of GAN training, HPO is framed as a stochastic ranking-and-selection (R&S) problem, and the Kim-Nelson indifference-zone procedure—well-established in discrete-event simulation—is adapted to GANs. Each hyperparameter vector is treated as an "alternative", with its mean performance estimated through repeated training runs using independent random seeds. The R&S method allocates additional replications only to candidates that remain competitive and halts once the probability of correct selection exceeds a user-defined threshold, providing finite-sample guarantees not available in standard HPO. This contribution offers a meta-level perspective on hyperparameter optimization, emphasizing not only which configurations yield the highest utility metrics but also how those metrics relate to the robustness of model performance under stochastic variation.

■ WB-07

Wednesday, 10:45-12:15 - Room: U2-205

Methods in Technical OR

Stream: Technical Operations Research
Invited session
Chair: *Ulf Lorenz*

1 - Balancing Equity and Efficiency in Optimal and Market-Based Control of Water Distribution Systems

Tobias Constantin Meck, Peter Pelz

Control of water distribution systems needs to meet various expectations, such as low power consumption of the involved pumps and high fulfilment rates during times of peak demand. In previous work, globally optimal solutions for these two objectives were presented for a simple model of a booster station for high-rise buildings. As uncertainties in the system impede the application of this optimal control in practice, an auction-based multi-agent approach was proposed, where the active components of the system, such as pumps and valves, trade volumetric flow rate guarantees on a common market.

In this work, we extend the previous approach by focusing on the fairness of flow distribution among different demand nodes. To this end, the original optimisation problem is extended to include a measure of equity as an additional objective, and the trade-off with efficiency and total fulfilment rates is explored. We show that the auction-based approach results in a reasonably equal distribution of demand fulfilment. Furthermore, it can be tuned to shift the focus towards other objectives, such as allowing more inequality to improve efficiency.

2 - Lothar Collatz: Mathematician, Scientist, V2-Ballistician, Professor

Ingo Althöfer

Lothar Collatz (1910-1990) was the youngest of three siblings. His family thought that he was sort of a mathematical Wunderkind. Shortly after his promotion to Dr.rer.nat. (1935 in Berlin, advised originally by Richard von Mises) Collatz in 1937 invented the now famous 3n+1-Problem as a mathematical puzzle.

With the 3n+1-rule a sequence of natural numbers is formed. If the current number n is even, it is divided by 2. However, if n is odd, 3n+1 is built. If the sequence reaches number 1, it enters the cycle 1-4-2-1. Collatz conjured that each starting value reaches 1 after finitely many steps.

Also in 1937, Collatz got his Habilitation degree in Applied Mathematics at TH Karlsruhe. In December 1939 he joined the large German rocket project (A4, later called V2 by the Nazis) und became its chief ballistician. After the end of World War II Collatz cleverly and with much energy covered his tracks in this project.

At the International Congress of Mathematics in Harvard (1950) he told many participants about the 3n+1 problem, partly to make sure that they would not ask him about the rocket project.

Being a successful Professor (first in Hannover, from 1952 on in Hamburg), Collatz had many academic students. In the "Mathematics Genealogy Project" 52 doctoral students and 1711 academic descendants are listed for him (as of 22 April, 2025).

In the talk important stations of his life are discussed. We also present new partial results for the 3n+1 problem.

Reference: I. Althoefer. Lothar Collatz zwischen 1933 und 1950 - Eine Teilbiographie. 3-Hirn-Verlag, 2019. Pages 1 - 46 of the book are digitally freely available at http://www.3-hirn-verlag.de/collatz-bis-seite-46.pdf

3 - The Template-Based Newspaper Layout Problem

Lennard Hansmann

Newspaper layout design involves a variety of decisions, from structuring pages to strategically placing content. The production of daily newspapers, whether in print or digital formats, requires the development of high-quality layout structures aimed at enhancing readability and maintaining aesthetic standards. In this work, we present a mathematical model aimed at optimizing template-based newspaper layout design. Our goal is to provide a practical solution that streamlines the selection of optimal layout variants, improves production processes in newspaper journalism, and enables automated layout generation.

■ WB-08

Wednesday, 10:45-12:15 - Room: H8

Vulnerable Healthcare Systems

Stream: Health Care Management
Invited session
Chair: *Emilia Grass*

1 - An Extended SEIR Model for Optimal Intervention to Comply with Healthcare Capacity and Personal Freedom During Pandemics
Laura Flinkert

In a pandemic, a high infection rate —referring to the rapid and extensive spread of the disease within the population—can lead to many individuals becoming ill at the same time, resulting in increased demand for medical and intensive care. This can cause the healthcare system to become overwhelmed, so the government must prevent it in order to guarantee that every patient receives proper treatment, thereby maintaining human dignity in care. The introduction of regulatory measures, such as contact restrictions, mask requirements, and hygiene measures slows down the disease spread and ensures the proper healthcare of citizens. At the same time, these measures are associated with restrictions on personal freedoms, such as freedom of movement and privacy, and are only justified during exceptional circumstances to protect public health. The approach to this dilemma—maintaining human dignity while simultaneously preserving individual freedoms—is solving an optimization problem. This problem is examined using an extended SEIR model that explains epidemiological relationships. To reflect the timing and impact of different measures, various interventions are introduced into the model at different points in time. The model also considers the maximum capacity of available intensive care beds, ensuring that the number of hospitalized individuals does not exceed this capacity at any point in time. Additionally, the measures should restrict personal freedoms only as much as necessary. Preliminary results regarding the determination of the optimal timing, duration, and nature of contact restrictions are presented.

2 - Quantitatively measuring cyber risk in healthcare
Aiman Zainab, Emilia Grass

Cyber attacks in healthcare are increasing rapidly, posing serious risks to patient safety and data security. Although numerous works are offering qualitative assessments of cyber risk, quantitative models remain rather under-researched. This work aims to cover the gap by using the FAIR model to assess cyber risk in healthcare with sector-specific risk scenarios quantitatively. However, as healthcare sector faces dynamic and unique loss, FAIR needs to be modified from its static loss nature to adapt to healthcare specific losses and operations. Among various risk assessment frameworks, the FAIR model offers a consistent approach to estimating cyber risk in financial terms that makes it an appropriate foundation for the purpose capable of extension. It also breaks risk into factors such as type of threat, vulnerabilities, and impacts that allow threat-specific modifications without breaking its logical framework. This feature of the model is suitable, particularly for healthcare where threats and impacts require individualized treatment and investment decisions are high priority. The study extends the implementation by incorporating dynamic intangible losses such as reputational damage, patient trust loss, and other operational damages alongside direct financial losses. In addition, it emphasizes the estimation of the frequency of loss events, which is crucial to determine the overall cyber risk incurred due to a cyber attack in healthcare, enhancing predictive power and decision-making accuracy. The sector-specific threat model framework will provide a more actionable overview of cyber risk, ultimately filling the void between cybersecurity measures and strategic risk management, and fostering resilience in highly sensitive sectors

■ WB-09

Wednesday, 10:45-12:15 - Room: H15

What's New in Solvers I

Stream: Software for Operations Research
Invited session
Chair: *Timo Berthold*

1 - What's New in FICO Xpress Solver 9.6?
Timo Berthold

We present the latest developments in the FICO Xpress Solver, featuring significant enhancements across its core algorithms for linear, mixed-integer, and nonlinear optimization. Key improvements include a new pre-root parallel heuristic phase, a deterministic work limit for reproducibility, and substantial performance gains in cut generation, presolving, and symmetry detection. Xpress 9.6 delivers strong performance improvements across all problem classes, including a remarkable 3x speedup in the global solver for non-convex MINLPs, further strengthening Xpress's capabilities for solving challenging optimization problems.

2 - A Whole New Look for CONOPT
Lutz Westermann, Renke Kuhlmann

Following GAMS' recent acquisition of CONOPT from ARKI Consulting & Development A/S, this presentation delves into the continuous evolution of this robust nonlinear optimization solver, emphasizing the advancements introduced in the latest release and the strategic implications of the new ownership.

The latest iteration of CONOPT introduces new APIs, e.g, for C++ and Python, opening up new possibilities for a clean, efficient, and robust integration into various software environments and projects requiring nonlinear optimization.

Finally, we will demonstrate the practical application of providing derivatives to CONOPT, an important step that is often necessary to achieve the best possible performance.

3 - Convexity detection in Hexaly
Michael Feldmeier

Hexaly is a mathematical optimization solver based on various operations research techniques, combining both exact and approximate methods such as linear programming, non-linear programming, constrained programming and primal heuristics. Knowing model features and recognizing special cases is imperative to selecting the right methods for solving the problem as fast as possible. One such model feature is convexity. Recognizing a convex model as such allows selecting more efficient algorithms under Hexaly's hood. In this talk we will present how Hexaly determines a user model's convexity. Convexity analysis typically examines the expression tree of the continuous relaxation of the model constraint by constraint. Combining knowledge of convexity-preserving operations with known properties of basic functions allows evaluating the curvature of complicated constraints and objectives. This can be straightforward to compute, e.g. positive sums of convex functions are convex. However, already for quadratic programmes convexity detection by this method can be ineffective: depending on the formulation of the functions as well as how they are translated into the expression tree it may not be possible to determine a convex problem as such. Of course, in the case of quadratic programming, spectral analysis can be applied. However, this is computationally expensive, and can sometimes be avoided, e.g. by application of Gershgorin's circle theorem. We will present data from numerical experiments about the reliability of our implementation of convexity detection in Hexaly.

■ WB-10

Wednesday, 10:45-12:15 - Room: H16

Collaborative delivery

Stream: Mobility, Transportation, and Traffic
Invited session
Chair: *Steffen Elting*

1 - On the Feasibility of Strategic Delivery Splitting: A Novel Approach to Improve Courier Availability in High-Demand Food Delivery Markets
Ann-Kathrin Meyer, Ekin Ugurel, Tobias Brandt

The rapid growth of online food delivery platforms has transformed food delivery from an occasional convenience to an essential aspect of urban food consumption. However, this expansion has introduced significant operational challenges, particularly during peak demand periods when courier availability becomes a major constraint. Traditional optimization strategies, such as batching orders, struggle to balance efficiency with courier availability. This study introduces strategic delivery splitting as a novel approach which divides deliveries into two segments—restaurant to transfer point and transfer point to customer—with different couriers handling each segment. By allowing couriers to remain closer to high-demand zones, this method reduces firstmile time and assignment delays, potentially improving overall system efficiency. Our research makes four key contributions. First, we develop an agent-based model based on real-world food delivery data from Meituan to simulate the delivery process. Second, we formalize the splitting decision as a partially observable Markov decision process and apply a Q-learning approach to derive an optimal policy. Third, we demonstrate that strategic splitting can reduce delivery delays by approximately 37% during courier shortages. Finally, we identify specific conditions under which this approach outperforms traditional direct delivery, providing actionable insights for food delivery platforms. Our findings have significant implications for risk management in food delivery operations. By optimizing courier allocation, strategic delivery splitting offers a robust solution for maintaining service quality during high-demand periods.

2 - Crowdshipping with joint deliveries and variable transfer points

Michel Jahns, Christian Bierwirth

To further uncover the potential of crowdshipping for e-commerce in urban areas, this study investigates how the performance of platforms, that offer crowdshipping services, can be enhanced. For this purpose, it explores how shipments that cannot be handled by a single occasional driver, also called crowdshipper, can be fulfilled through transport chains involving two or more cooperating crowdshippers. This form of crowdshipping, often referred to in the literature as joint delivery, is typically implemented using stationary or mobile transfer points, which usually also offers options for secure interim storage of deliveries if needed. In contrast, the present project considers direct handovers of packages at freely chosen locations. The approach not only increases flexibility but also eliminates the need to maintain secure storage facilities at designated transfer points. However, fully synchronizing the crowdshippers in both time and space significantly increases planning complexity. To address the associated optimization problem, a multi-stage heuristic solution approach is proposed. In this approach we first cluster crowdshippers, then generate delivery options, and finally solve the resulting winner determination problem using an appropriate metaheuristic. The implementation of the approach results promising solutions that are showing an acceptable tradeoff between computational time and solution quality.

3 - Questioning the Privacy Assumption: The Risk of Unintended Information Leakage in Auction-Based Carrier Collaborations

Steffen Elting, Jan Fabian Ehmke, Margaretha Gansterer

In the context of the climate crisis and a growing demand for efficient logistics, auction-based horizontal carrier collaborations have emerged as a promising solution to optimize delivery operations. These collaborations enable carriers to reallocate delivery orders among themselves, reducing costs and environmental impact. Despite their many benefits, combinatorial auctions might be vulnerable to a leakage of private carrier information, such as the locations of delivery orders that are not released for auction. This study investigates the extent to which these locations can be inferred by an auctioneer using data-driven optimization techniques, thus questioning the assumption of carriers having full control over the dissemination of their private information. The auctioneer cannot validate any location estimates it makes, since the true coordinates of unreleased orders are unknown. The only information available are the carriers' bids on order bundles, selected by the auctioneer. Thus, we propose a proxy objective that minimizes the loss between true and estimated bids by imitating a carrier's bidding process. Employing derivative-free black-box optimization methods, we find that the auctioneer can indeed infer spatial dispersion patterns, but that the precise identification of individual order locations remains challenging. The results underscore the need for further exploration of unwanted information leakage in seemingly privacy-preserving collaboration mechanisms and the development of robust frameworks that do not trade data security for collaboration gains. These findings contribute to the broader discourse on sustainable and efficient carrier collaborations, offering valuable insights for both researchers and practitioners in the field of city logistics.

■ WB-11

Wednesday, 10:45-12:15 - Room: U2-200

OR and the Global South 1

Stream: OR in Developing Countries
Invited session
Chair: *Gerhard-Wilhelm Weber*

1 - Assessing the Mutual Influence Among Strategies for Adopting Circular Economy: A Case from a Developing Country

Hadi Badri Ahmadi

Circular economy strategies optimize resource utilization, lower the requirement for raw materials and minimize waste. Nevertheless, studies focusing on the interactions and interrelationships among these strategies are scarce, particularly in emerging economies. To close this gap, this study develops a new approach for investigating the interactions and interdependencies among strategies for circular economy implementation using the DF-DEMATEL technique. According to the findings, "Investment in green technology" is the most critical strategy and needs significant attention for successfully implementing the circular economy. This research significantly assists industry decision-makers and specialists in developing economies to focus on the most critical strategies for promoting circular economy in their supply chains and move towards sustainable development.

2 - The Flood Fighting Problem: A Basic Model and Construction Heuristics

Karolin Eisele, Alf Kimms

Natural disasters such as floods occur more and more frequently due to climate change and claim many victims. If protective measures such as floodplains and dams are not sufficient or are damaged, emergency services must be deployed. In order to be able to deploy them as effectively as possible, we present a model for emergency response planning in the event of flooding. There are no studies on this topic in the literature to date. For water spreading we use a cell-based approach. We first present a basic model formulation. A priority rule procedure is developed and eight different priority rules are tested. A comprehensive calculation study illustrates the speed of the priority rules and identifies two rules as the best.

3 - Joint use of the ELECTRE Tri and KEMIRA-Sort Multi Criteria Decision Making methods to prioritize the exploitation of Non Timber Forest Products providing species

Stéphane Aimé Metchebon Takougang

The exploitation of non timber forest products (NTFPs) is an asset in the fight against poverty in rural areas of sub-Saharan Africa. Particularly in the Pô region of Burkina Faso, non-timber forest products (NTFPs) are the main source of income for rural populations. However, the potential of NTFP-providing species is not always exploited in a way that provides greater profitability for rural populations. The aim of this work is to propose a prioritization of NTFP-providing species based on their ability to provide greater profitability for local populations. To this end, a proposition of a methodology based on the joint use of the KEMIRA-sort and ELECTRE Tri multi-criteria sorting methods to assign NTFP-providing species to ordered categories of profitability is made. The application of this methodology enabled to identify a median categorization made up of three categories of NTFP-providing species according to their profitability in the Pô area. The best category is made up of one specie (tamarind), while the second best category is made up of four species (shea, baobab, moringa, mango) and the last of five species (nere, detarium, jujube, resin and liana). The concordance of these results with the estimate of the expert, playing the role of decision maker, at the very start of our study, validate empirically the proposed approach, prefiguring its successful application to other context of multi-criteria sorting problems in the future (e.g. prioritizing areas at risk of the spread of a given disease in public health).

■ WB-12

Wednesday, 10:45-12:15 - Room: H10

AI and Optimization for Warehousing

Stream: Artificial Intelligence, Machine Learning and

Optimization
Invited session
Chair: *André Hottung*

1 - Learning-Based Adaptive Large Neighborhood Search for Efficient Pod Repositioning in Robotic Mobile Fulfillment Systems

Lin Xie

The pod repositioning problem is a unique challenge in robotic mobile fulfillment systems (RMFS), notably exemplified by Amazon Robotics. In these systems, robots transport racks containing ordered items from the storage area to human pickers. Once the items are retrieved, an optimized decision must be made regarding the repositioning of the pods back into storage to maintain efficiency. Previous studies have addressed this problem using various heuristics.

In this work, we propose an adaptive large neighborhood search (ALNS) approach enhanced by deep reinforcement learning (DRL). Our method dynamically configures selection and acceptance parameters during each iteration, improving solution quality and adaptability. We evaluate our method against existing heuristic-based approaches in the literature, demonstrating its effectiveness in optimizing pod repositioning.

2 - Bringing Light to the Threshold: Evaluation of Production Policies using the Regression Discontinuity Design with Application to LED Manufacturing

Oliver Schacht, Philipp Schwarz, Sven Klaaßen, Martin Spindler

We investigate the impact of an inline rework step in a sequential lot-based manufacturing system. In this scenario, lots failing to meet specific quality thresholds, defined by multiple measurements, undergo rework to enhance quality and yield. As these thresholds are defined by a fixed value, it is challenging to compare lots with identical properties but different rework decisions. Thus, applying standard causal machine learning frameworks for estimating the rework effect and policy evaluation is difficult. We apply a framework featuring the regression discontinuity design (RDD) known from the econometrics literature to estimate the average treatment effect of the rework step locally at the cutoff. We employ recently developed approaches to improve estimation efficiency using machine learning algorithms in multi-dimensional RDD and provide insights into the expected effect of threshold adjustments on overall production yield. Additionally, we present effect identification results for multi-score RDD settings, commonly encountered in complex decision-making systems. Our simulated study using a digital twin offers practical insights for applying RDD in industrial data contexts. Finally, we apply our RDD framework to real-world data from opto-electronic semiconductor manufacturing at AMS Osram, featuring multiple RDD score dimensions, high-dimensional covariates, and fuzziness introduced by non-conforming units.

3 - Warehouse-Aware Design and Evaluation of Algorithmic Pipelines for Decision-Making in Warehouse Operations

Janik Bischoff, Hadi Kutabi, Maximilian Barlang, Özge Nur Subas, Uta Mohring, Fabian Dunke, Anne Meyer, Stefan Nickel, Kai Furmans

Optimization problems in warehouse operations—such as picker routing, order batching, and picker sequencing—are typically addressed sequentially rather than in an integrated manner, due to their high computational complexity. However, the quality of the overall solution produced by sequentially executed decision-making processes in warehouse operations depends on the selected combination of algorithms for the respective subproblems. Furthermore, it is not apparent which algorithms are applicable given a certain warehouse system or instance due to the missing semantic modeling of the warehouse context and algorithm requirements.

We aim to close this gap by developing a framework that can provide and evaluate all feasible algorithm combinations for a given warehouse system. The proposed methodology includes: (1) the semantic description of the warehouse system and required data; (2) mapping between the warehouse system and compatible algorithmic approaches; (3) design, automated synthesis, and efficient execution of algorithmic pipelines; and (4) selection of the best pipeline based on a comprehensive performance evaluation.

To showcase the effectiveness of our approach, we apply it to nine benchmark instance sets from the literature, covering the problem classes of order picking, joint order picking and batching, and picker sequencing. Consequently, this work contributes to the warehouse optimization literature by providing a generalizable framework for the design, automated synthesis, and selection of valid and well-performing algorithmic pipelines based on a warehouse context.

4 - Neural Deconstruction Search for Vehicle Routing Problems

André Hottung, Paula Wong-Chung, Kevin Tierney

Autoregressive construction approaches generate solutions to vehicle routing problems in a step-by-step fashion, leading to high-quality solutions that are nearing the performance achieved by handcrafted operations research techniques. We challenge the conventional paradigm of sequential solution construction and introduce an iterative search framework where solutions are instead deconstructed by a neural policy. Throughout the search, the neural policy collaborates with a simple greedy insertion algorithm to rebuild the deconstructed solutions. Our approach matches or surpasses the performance of state-of-the-art operations research methods across three challenging vehicle routing problems of various problem sizes.

Wednesday, 13:30-15:00

■ WC-01

Wednesday, 13:30-15:00 - Room: Audimax

Port and shipping logistics

Stream: Mobility, Transportation, and Traffic
Invited session
Chair: *Achim Koberstein*

1 - Minimizing Vehicle Delay Time in a Port Area Through Simulation Optimization of Traffic Light Control
Bruna Helena Pedroso Fabrin, Wolfgang Brüggemann, Larissa Timm, Alwin Brehde, Carsten Eckert, Ralf Sahling, Justin Wilckens, Julia Hertel, Ulrich Baldauf, Leif-Erik Gorris

In a port area, traffic demand can greatly vary depending on the hour of the day and travel direction. For example, more traffic can be expected in certain hours of the day in the direction of a terminal in order to unload or load cargo. This can lead to congestion and delays. Thus, drivers are more susceptible of being irritated or making mistakes due to staying too long in traffic. One way of working on this issue is by optimizing the traffic light control, so that traffic flow is considerably improved. This study is conducted within the IHATEC's HafenPlanZen project, which was developed to aid port planners in strategic decision making, such as traffic planning and adaptation. An important measure of traffic is Average Delay Time (ADT), which is defined as the extra time that vehicles need to complete their journey due to disruptions, such as congestion or traffic lights, in comparison to driving on a free path. This study had the goal of robustly minimizing the maximum ADT in a port area, because this represents the worst case of the rush hour traffic. To achieve this, we use a simulation optimization methodology and implement the Downhill Simplex Method. Results shows large improvements in travel times with maximum delay being about 5 times smaller than that of the initial solution considered.

2 - Automation of empty container repositioning at Maersk
Hamid Kharraziha

Due to trade imbalances, the container that remains empty after a goods transport often has to be repositioned before it can be used for a new transport. Repositioning of empty containers constitutes a significant part of the operational costs of a container shipping company and is at the same time a highly complex and interconnected global problem. This is called the Empty Container Repositioning Problem. I will give a brief description of how it is solved at Maersk and various challenges we have met on the way towards full automation. Maersk Line is one of the largest container shipping companies in the world.

3 - Model-driven fleet adaption in response to environmentally conscious customer demands
Justin Wittig, Christian Bierwirth

With the growing relevance of indirect emissions (Scope 3) in sustainability reporting, industrial shippers are increasingly motivated to opt for climate-conscious transport solutions. This trend puts pressure in freight carriers to progressively shift their fleet toward low-emission alternatives. During this transition both, conventional and low-emission vehicles operate in parallel, creating a complex planning environment that must accommodate varying customer expectations regarding emissions and cost. We address this problem by formulating a routing and assignment model based on the Set Partitioning Problem (SPP). This approach allow for the flexible selection of precomputed vehicle tours while incorporating different levels of fleet electrification and customer-specific trade-offs between environmental impact and transport costs. Our computational results, based on a collaborative planning scenario, show that strategies focusing solely on cost or emission fail when heterogeneous customer preferences are considered. Instead, integrating these preferences into fleet composition and routing decisions leads to more balanced and realistic logistics solutions.

4 - A Distributionally Robust Optimization Approach for Liner Shipping Fleet Repositioning
Jana Ksciuk, Achim Koberstein

Liner shipping repositioning is the costly process of moving container ships between services within a liner shipping network to adapt the network to fluctuating customer demands. Existing deterministic models for the liner shipping fleet repositioning problem (LSFRP) neglect the inherent uncertainty present in the input parameters. This paper introduces an optimization model for the stochastic LSFRP that addresses uncertainty concerning container demands and ship travel times. Two prevalent paradigms for tackling problems affected by uncertainty are classical stochastic programming (SP) and robust optimization (RO). However, SP often faces challenges with large-scale decision problems and the reliable estimation of the underlying probability distribution. In contrast, RO focuses on the worst-case scenario and is often considered overly conservative. We employ an alternative modeling paradigm known as distributionally robust optimization (DRO), which combines the strengths of SP and RO. DRO mitigates the "optimizer's curse" characteristic of stochastic programming by adopting a worst-case approach. Furthermore, distributionally robust models are often tractable and can be solved efficiently. We propose a two-stage distributionally robust optimization approach where we utilize the Wasserstein metric to construct an ambiguity set of possible distributions based on a single empirical distribution. The objective of the distributionally robust LSFRP is to minimize the worst-case expected cost with respect to this ambiguity set.

■ WC-02

Wednesday, 13:30-15:00 - Room: H4

Bilevel Optimization

Stream: Discrete and Combinatorial Optimization
Invited session
Chair: *Arie Koster*

1 - Solving the Partial Inverse Knapsack Problem
Nikolas Lykourinos, Andreas M. Tillmann, Maximilian Merkert, Eva Ley

We investigate the partial inverse knapsack problem. In this NP-hard bilevel optimization problem, the follower subproblem is a classical 0/1-knapsack problem with fixed item weights and item values, which are determined by the leader. Specifically, the leader problem is a partial inverse problem, i.e., the leader seeks a minimal change to given item values such that there is a follower optimum selecting or discarding items according to two given disjoint subsets. Partial inverse problems appear, e.g., in economic applications when a planner wants to incentivize rational followers to act in a desired way or to estimate unknown parameters in a model to (partially) explain certain observations such as market agent behavior. Based on a single-level mixed-integer formulation for the considered problem, we develop a branch-and-cut solution algorithm that utilizes a new exponential-size class of valid inequalities for the leader. We demonstrate in computational experiments that these cuts allow to reduce the number of iterations and the overall solution time.

2 - On the Complexity of the Bilevel Shortest Path Problem
Dorothee Henke, Lasse Wulf

We introduce a new bilevel version of the classic shortest path problem and completely characterize its computational complexity with respect to several problem variants. In our problem, the leader and the follower each control a subset of the edges of a graph and together aim at building a path between two given vertices, while each of the two players minimizes the cost of the resulting path according to their own cost function. We investigate both directed and undirected graphs, as well as the special case of directed acyclic graphs. Moreover, we distinguish two versions of the follower's problem: Either they have to complete the edge set selected by the leader such that the joint solution is exactly a path or such that the joint solution is a superset of a path. In general, the bilevel problem turns out to be much harder in the former case: We show that the follower's problem is already NP-hard here and that the leader's problem is even hard for the second level of the polynomial hierarchy, while both problems are one level easier in the latter case. Interestingly, for directed acyclic graphs, this difference turns around, as we give a polynomial-time algorithm for the first version of the bilevel problem, but it stays NP-hard in the second case. Finally, we consider restrictions that render the problem tractable. We prove that, for a constant number of leader's edges, one of our problem variants is actually equivalent to the shortest-k-cycle problem, which is a known combinatorial problem with partially unresolved complexity status. In particular, our problem admits a polynomial-time randomized algorithm that can be derandomized if and only if the shortest-k-cycle problem admits a deterministic polynomial-time algorithm.

3 - Neighbourhood-constrained Bilevel Shortest Path Problem
Szymon Wróbel, Adam Kasperski, Pawel Zielinski

The Shortest Path problem is one of the classical combinatorial optimisation problems that has been extensively studied in the deterministic setting, where the arc weights are precisely known. While this model is often sufficient, real-world applications frequently involve uncertainty, limited control over input data, or a partitioning of decision variables among multiple decision makers. One of the approaches suitable in that setting is bilevel optimisation – a framework in which the problem is divided into two hierarchically dependent subproblems.

In this work, we introduce a new problem: the Neighbourhood-Constrained Bilevel Shortest Path Problem (NCBSP), where the follower's decision space is restricted to the neighbourhood of the leader's decision. We present preliminary results on the computational complexity of the NCBSP and explore its relationships to other well-known optimisation problems.

4 - Automated Logic-Based Benders Decomposition
Vladimir Stadnichuk, Grit Walther, Arie Koster

We study Logic-Based Benders Decomposition (LBBD) for two-stage optimization problems, a generalization of traditional Benders decomposition to non-convexity in the second stage. Our focus is on two-stage problems with binary linking variables in the first stage and mixed-integer variables in the second stage, a setting where LBBD has been successfully applied to various applications. However, unlike conventional Benders decomposition, which benefits from automation within modern Mixed-Integer Programming (MIP) solvers, LBBD typically demands an intricate theoretical analysis to derive appropriate cut coefficients. This necessity presents significant barriers to practitioners aiming to utilize LBBD without extensive theoretical specialization. Against this background, we propose a novel framework capable of automatically generating Logic-Based Benders cuts using only the MIP formulations of both problem stages as input. Our methodology combines Benders, Lagrangian, and Dantzig-Wolfe decomposition techniques to project out the second-stage variables and generate LBBD cuts within a cutting-plane algorithm. We provide a comprehensive implementation of this framework in the Julia programming language, demonstrating that our approach can easily be implemented in state-of-the-art MIP solvers that support cutting-plane methods. Furthermore, our implementation includes multiple acceleration techniques, incorporating both newly-developed enhancements specifically tailored for our framework and established methods from existing decomposition literature. We also present some preliminary computational results.

■ WC-03

Wednesday, 13:30-15:00 - Room: H5

Energy planning and policy

Stream: Energy and Sustainability
Invited session
Chair: *Kathrin Fischer*

1 - Smart Meter Analytics and Tariff Design for Alleviating Energy Poverty: Evidence from a Clustering-Based Study in Montreal
Rahil Dejkam, Runming Jia, Reinhard Madlener

Energy poverty, defined as the inability to afford adequate energy services, poses serious health and comfort risks, particularly in regions with extreme climates. Traditional identification methods often rely on static income-based indicators, failing to capture real-time energy deprivation. This study leverages smart meter data from 5,984 households in Montreal to develop a data-driven approach for detecting and alleviating energy poverty. Daily electricity usage profiles are clustered using K-Means into low-, medium-, and high-load groups. Results show that energy-poor households typically fall into the low-load cluster and exhibit significantly lower consumption, even after controlling for living area. The model enhances the detection of energy-poor households by integrating floor space data and a direct energy deprivation metric. An Increasing Block Tariff (IBT) scheme is simulated to address their limited energy access. The results indicate that IBT increases electricity use while reducing annual expenditure for energy-poor households, without increasing average prices across the system. This research contributes a novel combination of clustering and pricing policy analysis to energy poverty research and demonstrates the potential of smart meter analytics for equitable energy policy design.

2 - What Are We Clustering For? Establishing Metrics and Performance Guarantees for Time Series Aggregation in Net-Zero Power System Optimization
Luca Santosuosso, Beltrán Castro Gómez, Bettina Klinz, Sonja Wogrin

The transition toward net-zero power systems necessitates high-fidelity optimization models that rely on high-resolution input time series of renewable generation, demand, and other exogenous factors. However, this leads to significant computational challenges, often rendering such models intractable. Time Series Aggregation (TSA) alleviates this issue by reducing temporal complexity through representative period selection via clustering. Yet, existing TSA methods have notable limitations. A priori methods focus solely on preserving the statistical properties of the input data, resulting in heuristics that lack theoretical guarantees on the accuracy of the aggregated model's output. In contrast, a posteriori methods directly aim to preserve the accuracy of the aggregated model, typically using the objective function as the sole evaluation metric. However, this may not align with the goals of all modelers, who often seek accuracy in specific decisions, such as technology- or region-specific investments, not directly captured by the objective function. This study revisits the TSA problem by tackling a key research question: What are we clustering for? First, we advance beyond the heuristic nature of a priori methods by introducing theoretically validated bounds on the objective function error for aggregated models in time-coupled mixed-integer power system investment planning problems. Second, we propose alternative evaluation metrics that reflect diverse modeling goals, beyond the objective function. Finally, we extend the theoretical guarantees of the proposed method to these metrics. Numerical results show the computational efficiency of the proposed TSA method and underscore the importance of metric selection to align with the specific goals of distinct modelers.

3 - Energy Management in Hubs for Circularity using a Modular Network Representation
Tobias Løvebakke, Daniela Guericke, Alessio Trivella, Devrim Murat Yazan

With the Clean Industrial Deal, the EU aims to increase its competitiveness while decarbonising its industrial sector. The EU has identified improving the efficient use of clean energy and integrating circularity into industrial processes as key measures. Hubs for Circularity (H4C) represent integrated systems that combine these strategies to enhance circular resource efficiency within a region. H4C benefit from the geographic proximity between different industries within industrial zones and the surrounding urban/rural areas allowing them to share resources, technology, and infrastructure and to operate under the principles of circular economy. Energy plays a significant role in H4C since the involved industries are often energy intensive. In this study, we investigate the operational synergies between energy supply and resource-sharing enabled by industrial-urban-rural symbiosis. To this end, we develop a stochastic, modular energy management model tailored for H4Cs. The model represents the hub as a network of nodes and arcs, where processes at each node convert incoming energy and resource flows into outputs, guided by modular process definitions. These modules capture operational characteristics such as ramping constraints, storage behaviour, and co-generation of resources. This structure makes the model applicable for analysing a variety of hub configurations with different technologies, while also accounting for uncertainties such as fluctuations in renewable energy production. By applying the model to a real life case study from the project "Sustainable Circular Economy Transition: From Industrial Symbiosis to Hubs for Circularity (IS2H4C)", we demonstrate how energy management in H4C support industrial-urban-rural symbiosis taking place within a hub.

4 - Modelling incentive mechanisms for grid-serving flexibility provision using bi-level programming with mixed-integer lower level
Tizian Schug, Kathrin Fischer

Transmission grid congestion management (CM) requires transmission system operators (TSOs) to adjust the market-based dispatch of individual generators in order to address transmission grid constraints in a cost-effective manner. As the grid experiences increased stress due to the integration of renewable energies and higher demand from flexible sector coupling technologies, there is an increasing need for innovative CM solutions to efficiently manage future grid bottlenecks. While flexible demand-side applications can further strain electricity grids, they also present new opportunities for TSOs to implement CM strategies. Employing incentive mechanisms could be a promising strategy to leverage demand-side flexibility for CM. The interactions of a TSO, an energy aggregator and the market following such an approach can be modelled as a bi-level program.

In this work, we explore the integration of battery storage systems (BESSs) into the model. By allowing integer variables in the lower level of the model, we gain advantages such as restricting arbitrage trading of the BESSs or incorporating more technical properties of other distributed energy resources involved in the CM process. However, this addition means that the commonly used reformulation based on the Karush-Kuhn-Tucker (KKT) conditions can no longer be applied to solve the model. To address this challenge, we present possible solution approaches from the literature and investigate them with respect to their applicability to the problem at hand. Finally, we draw conclusions on the potential of residential BESSs for congestion management in the transmission grid using the proposed incentive mechanism.

■ WC-04

Wednesday, 13:30-15:00 - Room: H6

Bilevel and Mixed-Integer Nonlinear Programming

Stream: Continuous and Global Optimization
Invited session
Chair: *Johannes Thürauf*

1 - Entropy Optimization using Convex Methods and Piecewise Linear Approximation
Paula Franke

Understanding statistical dependencies in biological sequence data can provide valuable insights for future treatments for viral diseases, for example HIV. The presentation covers the analysis and optimization of a real-valued entropy function for matrices as an analytical tool for virus studies. Specifically, we present a computational means to compare observed entropy values to the highest and lowest possible while maintaining normalized marginal distributions. The maximization problem can be rewritten as a convex minimization problem. Here, we show that the solution is bounded away from the nonsmooth part of the function, allowing for the implementation of a gradient-based solver. In the concave case, the entropy function is approximated by piecewise linear functions that are refined based on maximal error. This approach yields the implementation of an IP-formulation using SOS2-constraints. The convex and concave programs use the off-the-shelf solvers IPOPT and Gurobi, respectively, and are validated with test data points. Limitations of the implementations, in particular numerical accuracy, and validation through other methods are discussed and we will argue the reasonableness of the obtained results.

2 - Parametric Linear Programming Interdiction
Simon Wirschem, Alexey Bochkarev, Stefan Ruzika

We study the parametric linear programming interdiction problem, where an interdictor seeks to deteriorate the optimal objective value of a linear program using limited resources (budget). Interdiction problems are well-suited for detecting weak spots and to measure a system's robustness against worst-case influences. While most existing work on interdiction focuses on networks, we consider a more general setting where the follower solves an arbitrary linear program. In our formulation, the leader's budget acts as a parameter, allowing us to examine how the impact of interdiction evolves as this budget varies. This parametric perspective reflects a natural robustness analysis: any fixed budget represents an arbitrary threat level, whereas understanding the problem across a range of budgets offers deeper insight into the system's vulnerability and stability.

We show that the nonparametric version of this can be reformulated as a bilinear program, a well-studied class in the literature and which is known to be NP-hard. The computational complexity also carries over to our nonparametric sub-problem. Besides discussing the structure, we propose an exact branch-and-bound procedure along with numerical results. Our work enables the application of parametric worst-case analysis to the wide class of linear models, which holds potential applications in robustness, security, and adversarial optimization.

3 - Column-and-Constraint Generation for Robust Bilevel Optimization with Wait-and-See Follower
Johannes Thürauf, Henri Lefebvre

Bilevel optimization is a mathematical framework that allows modeling of hierarchical decision processes. Typically, it is assumed that all input parameters for both the leader and the follower are known when the leader makes a decision. However, in many real-world applications, the leader has to decide without fully anticipating the follower's response due to uncertainties in the follower's problem. In this talk, we address robust bilevel optimization problems in which the follower adopts a so-called wait-and-see approach. In this setting, the leader decides without knowledge of the specific realization of the uncertainty. Then, the uncertainty realizes in a worst-case manner, and afterward the follower makes their own decisions. For this challenging problem class, we discuss mathematical properties and present a corresponding solution approach based on column-and-constraint generation. The convergence of the proposed algorithm is discussed along with its practical implementation including numerical results.

■ WC-05

Wednesday, 13:30-15:00 - Room: H7

Multiobjective Decision Making and Integer Programming

Stream: Decision Theory and Multi-criteria Decision Making
Invited session
Chair: *Mick Stewart Wörner*

1 - Evaluation and Selection of Projects Using TOPSIS-MTPMMCBC with Mixed Multi Cost/Benefit Criteria and Integer Programming
Semih Eren Karakilic, Yasemin Arici

Companies are typically engaged in planning and executing projects. Due to developments such as the digitalization of business processes or diversification, there has been an observable increase in the number of projects to be evaluated. Since company resources are limited, their allocation must be carefully planned. Consequently, projects need to be evaluated based on realistic and transparent criteria in order to create an optimal project portfolio. We propose a robust and easily calibrated multi-criteria project evaluation model that encompasses evaluation factors such as the financial criterion measured by Net Present Value (NPV), Risk, Classification, Priority, Strategy, and Sustainability. The model utilizes the Technique for Order of Preference by Similarity to Ideal Solution with multi type projects multi mixed cost and benefit criteria (TOPSIS-MTPMMCBC). A feature of this approach is that the criteria values of the projects can have both negative and positive values. In the next step, the evaluated projects are utilized with Integer Programming (IP), considering constraints such as limited resources, to determine an optimal project portfolio. The model differentiates between optional and mandatory projects. In particular, the criterion of sustainability is gaining importance and becoming a key factor for businesses driven by political and social mandates. In the future, considering sustainability in decision making will become increasingly important and is therefore already integrated into this model. The proposed research may employ Key Performance Indicators (KPIs) as diverse criteria for decision-making. The criteria weights for the sample dataset were objectively calculated using the CRITIC method, and subsequently, a sensitivity analysis was performed.

2 - Towards application maturity of the classical diet model by integrating accurate nutrition data, personalization aspects and enhanced dietary variety
Mick Stewart Wörner, Taieb Mellouli

The classic Stigler-Dantzig diet model optimizes a mix of ingredients or meals to meet specified nutrient requirements. Previous studies of OR and nutritional scientists lack of realistic pricing and nutrient data and/or of fulfilling diverse, user-specific criteria. We formulate a linear model with both meal and ingredient levels, integrate real-world recipe and ingredient-to-nutrient data, and account for nutritional adequacy, user preferences, and balanced meal solutions. Ingredient price and nutrient data are taken from Open Food Facts database with prices regionally limited to Germany and France and nutrient values cross-validated using the USDA FoodData Central. Health-oriented nutrient constraint bounds are based on intake recommendations from the U.S. National Institutes of Health (NIH) and the World Health Organization (WHO), tailored by gender, age, and activity level. User preferences are modelled at both ingredient and recipe levels, distinguishing between exclusion-based constraints, e.g. veganism, and inclusion-based preferences, e.g. fish consumption or cultural cuisines. Piecewise linear penalties to discourage excessive repetition of recipes and cuisines, promoting dietary variety. Besides their individual level, nutrients are also constrained at group-level, e.g. limiting total fat to less than 30% of total caloric intake, saturated fats to less than 10%, and trans fats to less than 1%, as recommended by the WHO. Experimentation using accurate real-world data show how different dietary preferences, such as vegan, pescatarian, and Mediterranean diets, affect cost and nutritional quality of generated meal plans. Trade-offs in practical diet planning between dietary restrictions, cultural preferences, and financial feasibility are deduce

3 - Designing an Optimal hyperlocal distribution network to achieve operational efficiencies in context of Quick Commerce in India
Harpreet Kaur

Quick commerce has gained significant traction in the post-COVID era, particularly across Southeast Asian and European markets. Quick commerce or rapid delivery systems enables ultra-fast fulfilment of a wide range of products through a network of hyperlocal distribution centres often called dark stores. It is driven by the evolving consumer demand for speed and convenience. However, it is observed that many companies entering the quick commerce space struggle to achieve operational efficiency, often incurring substantial losses and, ultimately shut down. Selection of optimal dark store location and size directly impact speed, cost, and customer service level which can help companies in achieving operational efficiencies. This paper identifies and evaluates the key factors affecting dark store location selection within the complex urban and semi-urban regions of India. The factors were identified through an extensive literature review and semi-structured interviews with key industry stakeholders. The paper uses Decision-Making Trial and Evaluation Laboratory (DEMATEL) method to understand the complex interrelationships among criteria and evaluate the criteria. Further, Best-Worst Method (BWM) is used to evaluate and rank potential location alternatives. The resulting weights from BWM are then integrated into a multi-objective mixed-integer linear programming (MOMILP) model to optimize location decisions aligned with a firm's strategic goals. The proposed framework is demonstrated through a real-world case example. The findings indicate that selecting optimal locations for dark stores significantly enhances operational efficiency and maximizes the achievement of strategic objectives for the firm.

Keyworks: Rapid delivery, location selection, Q-commerce, MCDM, MOMILP

■ WC-06

Wednesday, 13:30-15:00 - Room: H9

Predictive Analytics: Forecasting I

Stream: Analytics, Data Science, and Forecasting
Invited session
Chair: *Thomas Setzer*

1 - Machine Learning for Lead-Time Demand Estimation: Addressing Data Sparsity in Spare Parts Inventory Control
Florian E. Sachs, Robin Reiners, Ulrich Thonemann

The cumulative distribution function (CDF) of lead-time demand lies at the core of any inventory control application. Traditionally, the inventory control literature has focused on deriving theoretical distributions for lead-time demand and forecasting future demand. However, recent developments advocate for direct empirical estimation—either by constructing empirical distributions through bootstrapping or by forecasting lead-time demand directly. In this study, we explore the potential of machine learning to enhance CDF estimation, particularly in settings with limited observational data, as is often the case for spare parts. We argue that a density-centric approach, specifically through nonparametric conditional density estimation (CDE), provides a richer and more nuanced representation of the uncertainties surrounding lead-time demand. We benchmark this method against recently proposed bootstrapping and direct forecasting techniques using real-world data, addressing the complexities arising from intermittent lead-time observations. In doing so, we aim to bridge the traditional focus on theoretical lead-time demand distributions with the growing emphasis on direct empirical estimation. Furthermore, by incorporating machine learning methods, we propose a novel and robust approach for estimating the CDF of lead-time demand.

2 - Intermittent demand forecasting with count panel data models
Katja Nieberle

Intermittent time series frequently occur in domains such as spare parts demand, service logistics, and slow-moving inventory systems, where demand is irregular and often zero. Most forecasting methods for intermittent demand time series use a univariate approach and estimate model parameters at the individual stock-keeping unit (SKU) level. Due to the high frequency of zero demand, it is often impossible to capture underlying trend- and season-parameters or local patterns, which may be visible at higher levels of product hierarchies. We present a multivariate approach for forecasting groups of intermittent demand time series with similar patterns. We use count panel data distributions, in which both individual parameters and common parameters at the aggregated hierarchy level are estimated simultaneously. Our approach is tested against commonly used intermittent demand forecasting methods.

3 - Conditional volatility modeling and financial risk measurement via recurrent neual networks
Theo Berger

We assess both simulated and empirical economic time series and discuss the application of recurrent neural networks to identify different volatility regimes of financial time series. We study statistical properties of the residuals to analyze the precision of competing concepts for conditional volatility modeling. Also, we demonstrate the application of financial risk measurement in comparison with econometric benchmarks.

The simulation assessment demonstrates that there exists a trade-off between insample accuracy and the detection of autocorrelation. We also introduce recurrent neural networks to a Value-at-Risk universe and demonstrate that recurrent neural networks describe a promising alternative to the econometric GARCH approaches for small training samples.

■ WC-07

Wednesday, 13:30-15:00 - Room: U2-205

OR with Technical Constraints

Stream: Technical Operations Research
Invited session
Chair: *Lena Charlotte Altherr*

1 - Optimization of Adaptive Truss Structures for Robustness and Manufacturability in Bending Applications
Julian Mrochen

The increasing demand for individualized products, small batch sizes, and modular system diversity is driving a shift from mass production to flexible and scalable manufacturing. We propose a nonlinear optimization model for truss structures that integrates static, elastostatic, and manufacturing constraints to ensure structural robustness and manufacturability. A key aspect of our approach is the precise calculation of compliance values, which play a critical role in bending processes. Building upon this foundation, we extend our model to incorporate movable structural elements, further enhancing the adaptability and efficiency of truss systems under dynamic loading conditions. By incorporating adjustible components into the truss system, we improve load distribution and flexibility. These elements primarily serve to increase tool flexibility in bending applications, enabling the adaptation to different bending contours using a single tool. This study highlights the potential of mathematical optimization as a powerful tool in modern structural engineering, enabling more adaptive and resource-efficient solutions for advanced manufacturing applications.

2 - Performance analysis of a bulk arrival single server queue with server breakdown under Bernoulli and randomized vacation policies.

Anjana Begum

This research study examines an unreliable non-Markovian single server queue subject to delayed repair, rendering two heterogeneous services with an optional re-service facility. The server considered here undergoes both exhaustive vacations following the Bernoulli trial during a busy period and non-exhaustive vacations following a randomized policy after a busy period. Using the supplementary variable technique, a thorough study of the proposed model is conducted. The probability generating function of the queue size distribution at random and service completion epoch along with the mean queue size are determined. Besides, the busy period distribution and waiting time distribution are accomplished in the study. A suitable linear cost structure of the underlying model is developed to obtain an optimal randomized policy at a lower cost. Finally, some numerical investigation is carried out to demonstrate the model's applicability.

■ WC-08

Wednesday, 13:30-15:00 - Room: H8

Patient Flow Optimization

Stream: Health Care Management
Invited session
Chair: *Anne Zander*

1 - On Surgery Ward Resilience: Quantitative Concepts, Evaluation, and Analysis

Gabriela Ciolacu, Siamak Khayyati, Emilia Grass

Effective surgical ward management in the context of adverse events is especially challenging. It requires balancing meeting uncertain and increasing patient demand with limited and costly resources for prolonged periods. To evaluate if the ward can meet sudden demand for surgical care without straining medical resources during an event, hospital decision-makers introduced resilience to dynamically assess the event's impact, considering that the ward is the costliest medical unit. Resilience is the surgical ward's capacity to prepare (1), withstand (2), absorb (3), and recover (4) from adverse events such as natural disasters, implying multiple phases.

This study examines quantitative resilience indicators and their application to surgical wards following adverse events. While reviewing 30 healthcare resilience publications, we noticed that quantitative evaluation heavily depends on the definition of the performance indicator. To the best of our knowledge, the current state-of-the-art healthcare excludes surgical care, focuses on performance assumptions derived from engineering systems (e.g., energy) that significantly differ from healthcare, and relies on cumulative resilience indicators, neglecting the four aforementioned phases. To account for such shortcomings and guided by literature, this study proposes a quantitative evaluation that provides a granular resilience indicator, including all phases. The study also tailors the indicator and its interpretation to the surgical ward. We illustrate the usefulness of the proposed evaluation in a simulation that models the surgical ward and adjacent units in the context of an adverse event as a queueing network.

2 - A Scenario-Based Solution Approach for a Stochastic Operating Room Allocation Problem

Duygu Tas, Raf Jans

This study addresses an operating room (OR) allocation problem where surgery durations are stochastic and the planning horizon spans multiple periods (e.g., five days). The inherent uncertainty in surgery durations may lead to delays in surgery start times and cause ORs to exceed their capacity. To tackle these challenges, we propose a model that incorporates both the fixed costs of opening ORs and the penalty costs related to expected overtime of ORs and expected delays in surgery start times. These expected values are exactly computed using a procedure that (i) assumes surgery durations follow a given probability distribution and (ii) applies the hospital's "to-follow" policy. In this policy, commonly used in real-world hospital settings, once a surgery is completed in an OR, the next scheduled surgery starts immediately with no waiting time between surgeries. To solve this stochastic problem, we introduce a scenario-based approach, using a two-stage stochastic programming model that is solved based on a set of sample scenarios. We conduct computational experiments on newly generated instances, followed by extensive analysis of the results.

3 - Optimizing Patient Flow: Predicting and Managing Aftercare Demand to Tackle Hospital Bed-Blocking

Anne Zander, Anouk Beursgens, Richard Boucherie, Aleida Braaksma

As the demand for elderly care increases and healthcare resources become more strained, ensuring an efficient transition from hospital to aftercare becomes vital. Elderly patients often require care provided by aftercare organizations, such as nursing and care homes, and home care after hospital discharge. However, limited aftercare capacity often leads to bed-blocking: patients occupying hospital beds longer than medically necessary. This research addresses the issue by taking a system-wide perspective, combining aftercare demand prediction with capacity planning in aftercare, assuming collaboration between hospitals and aftercare organizations. Using hospital data, we predict aftercare demand on different time scales (short-term, mid-term, and long-term), which provides input for capacity planning in aftercare. In this talk, we focus on long-term, strategic bed capacity planning in aftercare. We model the hospital aftercare system as a modified call-packing system, taking into account that the time spent in the hospital may contribute to the patient's recovery process to a certain extent. We propose a modified offered load approximation on the basis of which we can optimize aftercare capacity. Our first numerical results show a significant reduction in costs, which include costs for blocked beds in the hospital and costs for empty beds in aftercare, as well as bed-blocking. In conclusion, by aligning hospital and aftercare operations, we seek to reduce bed-blocking, improve patient flow, optimize resource use, and enhance care quality.

■ WC-09

Wednesday, 13:30-15:00 - Room: H15

What's New in Solvers II

Stream: Software for Operations Research
Invited session
Chair: *Stefan Vigerske*

1 - The SCIP Optimization Suite 10

Stefan Vigerske

In this year, the SCIP Optimization Suite reaches its first double-digit major version number. Starting with an algebraic modeling language, a simplex solver, and a constraint integer programming framework, it has evolved over the last 20+ years into a swiss army knife for anything where relaxations are subdivided, trimmed, generated dynamically, and eventually solved, be it on embedded, ordinary, or supercomputers. The newest iteration brings major updates for the presolving library PaPILO, the generic decomposition solver GCG, and the branch-cut-and-price framework SCIP itself. In this talk, we will give a short overview on the current SCIP Optimization Suite ecosystem and catch a glimpse on the new features contributed by over 15 developers in the newest major release.

2 - Software for Verified Optimization of Mixed-Integer Linear Programs

Ambros Gleixner, Leon Eifler, Alexander Hoen, Magnus Myreen, Yong Kiam Tan

Standard solver software for mixed-integer linear programming relies on floating-point arithmetic and defines feasibility and optimality of solutions within numerical tolerances. The correctness of its results, even within these tolerances, is subject to roundoff errors. In this talk, we give an overview of numerically exact software for solving mixed-integer linear programs without tolerances and for verifying the correctness of the result. In particular, we highlight the exact functionalities of the newly released version 10 of the open-source MIP solver SCIP.

3 - What's New in GCG 4?
Erik Mühmer, Marco Lübbecke, Til Mohr, Chantal Reinartz Groba

GCG is a generic branch-cut-and-price solver for mixed-integer linear programs (MILPs). It is built on SCIP and is capable of performing a Dantzig-Wolfe reformulation automatically. GCG reformulates MILPs by either automatically detecting inherent structures or utilizing user-defined ones. This presentation will highlight key features introduced in GCG 4. First, GCG 4 supports nested decompositions allowing users to specify complex decomposition hierarchies using a new JSON-based file format. If a nested decomposition is available, GCG applies the inner (potentially nested) decompositions to the corresponding pricing problems. Additionally, GCG 4 introduces an API enabling users to integrate custom branch rules and separators that work directly on the master problem. As such branching decisions and cutting planes may not translate back to the original problem, they require special handling. GCG 4 offers an API for creating and adding so-called extended master constraints. It hides additional overhead by enabling users to create constraints or rows along with necessary pricing problem modifications. GCG automatically applies these modifications if the constraints or rows are active to ensure that the pricing process respects the additional constraints. Moreover, priced variables are added to the constraints via user-defined callbacks. We will demonstrate these features through practical use cases and share insights from conducted experiments.

4 - Recent Advances in Flowty
Simon Spoorendonk

Flowty is a solver tailored to structured network optimization problems. By combining graph-based modeling with column generation, it enables scalable formulations for problems involving flows, paths, and resource constraints. Constraints are modeled directly on graph elements and traditional integer variables, allowing for expressive yet compact models.

Recent developments have focused on improved strategies for solving various multi-commodity flow network problems—with and without resource-constrained paths—an important core challenge in middle-mile transportation networks, among others.

In this talk, we present the latest algorithmic enhancements and share recent benchmark results demonstrating Flowty's performance improvements.

■ WC-10

Wednesday, 13:30-15:00 - Room: H16

Tour Planning Problems

Stream: Mobility, Transportation, and Traffic
Invited session
Chair: *Marlin Wolf Ulmer*

1 - The Truck-Drone Hurdle Relay Problem in a Euclidean Space
Christin Münch, Alf Kimms, Fabian Wilschewski

We present a mixed-integer linear program (MILP) for the Truck-Drone Hurdle Relay Problem in a Euclidean space, which is particularly relevant in the context of disaster relief. In this problem, a drone is tasked with the delivery of relief supplies in a disaster-stricken area, while being supported by trucks along its way with transportation and battery exchanges. Trucks and drone need to work together, as the partially damaged road network prevents the trucks from reaching the destination, and as the distance from the depot to the destination is far too great for the drone to cover in one flight. We abstain from the common assumption in truck-drone delivery that vehicles operate on a graph and use a geometric approach with drone trajectory planning instead. Furthermore, we consider the following aspects: i) obstacles with which the drone must not collide, ii) continuously formulated roads, so that the drone can be launched and recovered from any position along the roads, iii) a service time for the battery exchange, and iv) a drone energy consumption dependent on velocity. The objective is for the drone to deliver the relief supplies as fast as possible.

2 - An Electric Ride-Hailing System with Modular Vehicle Convoys for Rural Regions
Philipp Speckenmeyer, Miriam Stumpe, Levi Kletetzka, Guido Schryen

Providing sustainable and flexible on-demand mobility solutions in rural areas remains a major challenge due to low population densities and limited public transport options. One promising concept is a modular, on-demand transportation system consisting of small, autonomous electric vehicles that can dynamically couple and decouple, enabling scalable capacities to improve occupancy rates and reduce energy consumption per passenger-kilometer. Such a system is currently being developed in the NeMo.bil project. In this context, we consider the resulting operational planning problem, which extends traditional dynamic ride-hailing with electric vehicles by additionally incorporating decisions on convoy formation. Given a daily demand scenario, operational area, and modular vehicle fleet, we formulate the planning tasks as a combination of vehicle assignment, charging scheduling under range constraints, and convoy formation decisions. To cope with the complexity of real-time, dynamic request arrivals, we model the system as a Sequential Decision Process (SDP) and develop a policy-based solution approach that enables rapid operational decision-making. Our policy aims to optimize system efficiency — such as minimizing total fleet travel distance — while ensuring high service quality, including low request rejection rates. We evaluate our approach by integrating the decision policy into the SUMO simulation framework, using demand data derived from a real-world on-demand shuttle service operating in Höxter, Germany. We compare the performance of our method with that of the existing system.

3 - Online Robust Capacitated Team Orienteering Problem
Siamak Khayyati, Masoud Shahmanzari, Jyotirmoy Dalal, Davood Shiri

We introduce an online robust optimization extension of the Capacitated Team Orienteering Problem, called ORCTOP. We hedge against uncertainties in four key parameters: prizes, demand weights, service times, and travel times. We characterize uncertainty as a budget uncertainty set and analyze the problem in an online setting where uncertain parameters are revealed sequentially to the decision maker. We investigate ORCTOP through the lens of competitive ratio (CR) and, to reduce the inherent over-conservatism of this measure, adopt a novel setup-based analysis that evaluates algorithmic performance relative to each specific problem instance. We derive a theoretical lower bound on the setup-based CR of the optimal online algorithm for ORCTOP, quantifying the maximum potential advantage of having complete prior information in the worst case. We propose two formulation-based algorithms—one static and one adaptive—with provable setup-based CR guarantees, each matching our proposed lower bound. We extend our theoretical analysis by evaluating average case performance and proving that the adaptive algorithm outperforms the static one in terms of average-case CR. To enable real-time deployment, we develop robust evolutionary heuristics to efficiently approximate the solutions of both of our proposed formulation-based algorithms in real time. We test our proposed algorithms using a dataset derived from real-world urban networks in cities affected by the 2023 Türkiye earthquake. We confirm the effectiveness of our proposed heuristics by comparing them with our mathematical formulations through extensive computational experiments. Our empirical results demonstrate that the adaptive algorithm consistently outperforms the static algorithm in terms of average-case CR.

4 - Learning State-Dependent Policy Parametrizations for Dynamic Technician Routing with Rework
Marlin Wolf Ulmer, Jonas Stein, Florentin Hildebrandt, Barrett Thomas

Home repair and installation services require technicians to visit customers and resolve tasks of different complexity. Technicians often have heterogeneous skills. The geographical spread of customers makes achieving only "ideal" matches between technician skills and task requirements impractical. Additionally, technicians are regularly absent, e.g., due to sickness. With only non-ideal assignments regarding task requirement and technician skill, some tasks may remain unresolved and require a revisit and rework at a later day, leading to delayed service. For this sequential decision problem, every day, we iteratively build tours by adding "important" customers. The importance bases on analytical considerations and is measured by respecting urgency of service, routing efficiency, and risk of rework in an integrated fashion. We propose a state-dependent balance of these factors via reinforcement learning. We rely on proximal policy optimization (PPO) tailored to the problem specifics, analyzing the implications of specific algorithmic augmentations. A comprehensive study shows that taking a few non-ideal assignments can be quite beneficial for the overall service quality. Furthermore, in states where a higher number of technicians are sick and many customers have overdue service deadlines, prioritizing service urgency is crucial. Conversely, in states with fewer sick technicians and fewer customers with overdue deadlines, routing efficiency should take precedence. We further demonstrate the value provided by a state-dependent parametrization via PPO.

■ WC-11

Wednesday, 13:30-15:00 - Room: U2-200

OR and the Global South 2

Stream: OR in Developing Countries
Invited session
Chair: *Gerhard-Wilhelm Weber*

1 - An example of using the Biform game concept in the analysis of the co-opetition phenomenon between technology companies in Poland

Jacek Dominik Śledziński, Magdalena Graczyk-Kucharska, İsmail Özcan, Gerhard-Wilhelm Weber

Coopetition—the simultaneous cooperation and competition between firms—is increasingly observed in the technology sector, particularly in developing countries. Traditional approaches in game theory, based on a strict division between cooperative and non-cooperative games, do not fully reflect the complexity of business relationships in dynamic market conditions.

In response to this challenge, the paper presents an example of using the Biform Games concept—a model that integrates a non-cooperative phase followed by a cooperative one—to analyze strategic interactions between two Polish technology firms (IT sector). The case study focuses on companies competing for a similar client base, while also considering collaboration if mutually beneficial.

The Biform model captures the key transition from competition to cooperation, identifying conditions under which collaboration becomes more profitable. The analysis makes it possible to determine optimal strategies depending on changing market conditions and the balance of power between players.

The results confirm the usefulness of the Biform Games approach in describing and predicting coopetitive behavior in highly dynamic economic environments. The model offers valuable analytical support for operational research focused on fostering inter-firm collaboration in developing economies.

2 - OR, in Europe and worldwide, for Development and Developing Countries, yesterday, today and tomorrow

Gerhard-Wilhelm Weber

EURO Working Group on Operational Research for Development (EWG-ORD) was established within the Association of European Operational Research Societies (EURO) during EURO 2006 in Iceland. Its aim is to promote and facilitate communication links among European and other researchers working in areas of operational research (OR) for development. EWG-ORD has organized annual workshops, e.g., ICORD workshops with IFORS, to promote the importance of OR in improving the lives of people in developing and developed countries, as well as streams at EURO, IFORS and other conferences. From the beginning, EWG ORD was very international and global, which led to numerous developmental impulses worldwide. This enriched IFORS itself, its regional groupings, numerous national OR societies, other EWGs and further groups, universities and organizations, sciences and disciplines, and always the lives of the local people. IFORS has a dedicated section "Developing Countries online resources" which serves as a platform to provide widespread access to free and publicly-available OR materials for development to the entire OR community, including researchers and practitioners in the Developing Countries (DCs). It has now reached 1 million visitors. Among the many collaborators and supporters were E. del Rosario, S. Merchant, L. White and H. Smith. We would like to thank them all very much. This presentation provides details, examples and future challenges of OR for Development.

■ WC-12

Wednesday, 13:30-15:00 - Room: H10

Explainability and Interpretability in Optimization

Stream: Artificial Intelligence, Machine Learning and Optimization
Invited session
Chair: *Daan Otto*

1 - Interpretable Surrogates for Optimization

Sebastian Merten, Marc Goerigk, Michael Hartisch, Kartikey Sharma

An important factor in the practical implementation of optimization models is their acceptance by the intended users. This is influenced by various factors, including the interpretability of the solution process. A recently introduced framework for inherently interpretable optimization models proposes surrogates (e.g. decision trees) of the optimization process. These surrogates represent inherently interpretable rules for mapping problem instances to solutions of the underlying optimization model. In contrast to the use of conventional black-box solution methods, the application of these surrogates thus offers an interpretable solution approach.

Building on this work, we investigate how we can generalize this idea to further increase interpretability while concurrently giving more freedom to the decision maker. We introduce surrogates which do not map to a concrete solution, but to a solution set instead, which is characterized by certain features. Furthermore, we address the question of how to generate surrogates that are better protected against perturbations. We use the concept of robust optimization to generate decision trees that perform well even in the worst case. For both approaches, exact methods as well as heuristics are presented and experimental results are shown. In particular, the relationship between interpretability and performance is discussed.

2 - Counterfactual Explanations in Regression

Matthias Soppert, Alexandre Forel, Thibaut Vidal, Maxime Cohen

Accurate predictions of real-valued quantities form the basis for data-driven decision-making in many applications across all industries. For example, online retailers as well as classical brick-and-mortar stores require accurate demand predictions for effective operations management, such as pricing and inventory control. Often, however, the best performing models regarding prediction accuracy are opaque and, thus, are considered as black boxes by the user. We propose a framework based on mixed-integer programming that increases the explainability of a wide range of state-of-the-art regressors, including random forests, gradient boosting regressors, and certain artificial neural networks. The framework is based on the determination of counterfactual explanations - an established approach to improve explainability. It yields answers to questions of the form "what is the minimum required change of a certain model input such that the model's prediction exceeds a specific target output?". Thus, the answers are optimal with regard to the required model input change. For example, for a given vector of product features and context information as well as its predicted sales volume, the optimization returns the closest alternative vector that results in a specific desired minimum sales volume. Asking such counterfactual questions and analyzing their respective answers helps to explain the input-output relations that a trained regressor has learned, but they can also directly be used in decision-making - in the above example possibly regarding marketing activities.

3 - Coherent Local Explanations for Mathematical Optimization

Daan Otto, Jannis Kurtz, Ilker Birbil

The surge of explainable artificial intelligence methods seeks to enhance transparency and explainability in machine learning models. At the same time, there is a growing demand for explaining decisions taken through complex algorithms used in mathematical optimization. However, current explanation methods do not take into account the structure of the underlying optimization problem, leading to unreliable outcomes. In response to this need, we introduce Coherent Local Explanations for Mathematical Optimization (CLEMO). CLEMO provides explanations for multiple components of optimization models, the objective value and decision variables, which are coherent with the underlying model structure. Our sampling-based procedure can provide explanations for the behavior of exact and heuristic solution algorithms. The effectiveness of CLEMO is illustrated by experiments for the shortest path problem, the knapsack problem, and the vehicle routing problem using parametric regression models as explanations. The concept of CLEMO can be extended to provide explanations using decision tree models, as we will show.

4 - Artificial human intelligence: Replicating human decision making for a driving assistant by combining knowledge engineering, computer vision and rule-based inference
Robert Maximilian Neumann, Taieb Mellouli

A vast majority of modern AI-based approaches to decision making create a so called 'blackbox' where the inputs lead to a result with little to no understanding why. This is a common design choice for AI in complex problems, making the learning algorithm learn the desired outcome all the way. We differ from this common approach by splitting the decision making into two phases and using knowledge engineering to define relevant information (features) and a set of rules based on them in order to replicate the decision process made by humans more closely. We apply our concept within a driving assistant whose task is the determination of the adequate speed given an image (and some timeconsistent information).

The foundation of our approach are the rules and the features they require, which we acquired using knowledge engineering, input from human experts and the german traffic law (STVO). In the first phase our approach creates a vector of these abstract features that represent the current situation given in an input image. For this task we use state of the art computer vision algorithms. In the second phase we apply our defined rules to deduce a speed recommendation. The deduction process is split into two parts where the first updates the timeconsistent knowledge base which is then used to infer the actual recommended speed. This approach is inspired by the research of Walther and Mellouli and will in future research be extended by learning algorithms to analyze and enhance the rule set used for decision making.

Wednesday, 15:15-16:00

■ WD-01

Wednesday, 15:15-16:00 - Room: Audimax

Semi-plenary talk Barbosa-Póvoa

Stream: PC Stream
Semi-plenary session
Chair: *Dominik Möst*

1 - Sustainable Supply Chain Optimization: From Closed-Loop to Green Energy Networks
Ana Barbosa-Póvoa

Sustainability is a major concern in supply chain management, driving the need to integrate sustainable practices into supply chain design and operations. One approach is the development of closed-loop supply chains, which focus on material recovery and circularity, along with renewable energy supply chains, such as those supporting hydrogen-based systems. However, supply chains are inherently complex, and this complexity increases in sustainable networks due to the interplay of economic, environmental, and social objectives. To address these challenges, Operations Research (OR) methodologies provide a foundation for developing decision-support tools, incorporating modeling and optimization to enhance the design and management of sustainable networks. Within this context, this talk explores how optimization techniques can support strategic and tactical decision-making in sustainable supply chains. Additionally, it discusses key research challenges and future opportunities to advance truly sustainable supply chains.

■ WD-02

Wednesday, 15:15-16:00 - Room: H4

Semi-plenary talk Harper

Stream: PC Stream
Semi-plenary session
Chair: *Rainer Kolisch*

1 - OR saves lives!
Paul Harper

I will discuss several related research projects, broadly within emergency and urgent healthcare services. This includes working with ambulance providers and the Indonesian Government to help them make critical decisions on the optimal types, capacities and geographical locations of response vehicles. Such factors directly impact on the probability of patient survival, ability to respond to major disasters, and the overall quality of care provided. There are however many challenges faced in Indonesia, including vast geographical areas, traffic congestion, inadequate numbers of ambulances and a lack of a co-ordinated service.

■ WD-05

Wednesday, 15:15-16:00 - Room: H7

Semi-plenary talk Misener

Stream: PC Stream
Semi-plenary session
Chair: *Marc Goerigk*

1 - Bayesian optimization for mixed feature spaces using tree kernels and graph kernels
Ruth Misener

We investigate Bayesian optimization for mixed-feature spaces using both tree kernels and graph kernels for Gaussian processes. With respect to trees kernels, our Bayesian Additive Regression Trees Kernel (BARK) uses tree agreement to define a posterior over sum-of-tree functions. With respect to graph kernels, our acquisition function with shortest paths encoded allows us to optimize over graphs, for instance to find the best graph structure and/or node features. We formulate both acquisition functions using mixed-integer optimization and show applications to a variety of challenges in molecular design, engineering and machine learning.

The tree kernel work is joint with Toby Boyne, Alexander Thebelt, Jose Folch, Calvin Tsay, Robert Lee, Nathan Sudermann-Merx, David Walz, and Behrang Shafei.

The graph kernel work is joint with Yilin Xie, Shiqiang Zhang, Jixiang Qing, and Calvin Tsay.

■ WD-09

Wednesday, 15:15-16:00 - Room: H15

Gurobi Workshop

Stream: PC Stream
Workshop session
Chair: *Robert Luce*

1 - Solving LPs and MIPs with Gurobi on the GPU: What's in for me?
Robert Luce

Recent GPU hardware generations offer high compute throughput for many applications in machine learning, scientific computing, and beyond. How does this new compute power translate into improvements in solving real-world linear and mixed-integer optimization problems in practice?

In this workshop, we review Gurobi's efforts and research findings on solving optimization problems on the GPU. We touch interior point methods, first-order methods, and relaxation-based MIP heuristics, and we frame these in terms of their applicability and usability on the GPU. Also, we discuss a few implementation aspects that only arise when implementing such traditional methods on the GPU.

Finally, we'll showcase how Gurobi's preliminary GPU-based components compare, performance-wise, to our standard CPU-based counterparts across a wide range of real-world models.

Wednesday, 16:30-18:00

■ WE-01

Wednesday, 16:30-18:00 - Room: Audimax

Delivery problems

Stream: Mobility, Transportation, and Traffic
Invited session
Chair: *Ninja Scherr*

1 - The dynamic same-day delivery problem with walking, parking and stochastic customer requests
Ninja Scherr, Sara Reed, Ann Campbell, Barrett Thomas

Due to the rise in e-commerce sales, logistics service providers need to transport increasing volumes of goods to customers' homes. In addition, the trend for same-day delivery leads to shorter, more fragmented delivery tours as well as dynamic decision making on when to dispatch vehicles. These shorter delivery tours typically exhibit smaller consolidation potential leading to inefficient use of the delivery driver. Thus, delivery companies seek ways to improve routes to best use drivers' available time. One aspect still not considered widely in the same-day delivery research is the difficulty of parking. Often, same-day delivery models assume that the delivery driver can park at each customer location to deliver the goods. However, in many cities, parking spaces are scarce and congestion leads to longer parking search times. When planning delivery tours in such settings, a more efficient approach may be to park once and deliver packages to several customers by foot from that parking spot. Yet, most models in the same-day delivery literature also do not consider walking by the driver. In this talk, we present the same-day delivery problem with walking, parking, and stochastic customer requests. In this problem, customers request service and expect delivery on the day of their order. The service provider may aim to maximize the overall profit or the number of customers that can be accepted over the day with given resources. We describe the problem and model it as an MDP. Then, we propose different policies for the problem that differ in how they delay the dispatching of the delivery vehicle. In a computational study, we show the impact of the different policies on the number of accepted customers, tour lengths, and overall costs for different parking search times.

2 - Integrated Delivery Management and Vehicle Routing for Parcel Lockers
Jim Schoppa, Robert Klein

In light of labor shortages, rising fuel costs, and thin profit margins, providers of last-mile delivery services face mounting pressure to innovate. One avenue to more efficient last-mile operations is incorporating out-of-home delivery (OOHD) services. In particular, the delivery to parcel lockers, instead of customers' homes, is becoming more popular. When operating a system of parcel lockers, the providers face a number of challenging decision problems, from the strategic to the operational level. On a specific day, they have to decide which parcels to deliver to which locker, which compartments to use, when to visit a locker, and which routes the delivery vehicles should take. This problem is challenging because parcels arrive at the depot throughout the day and may be assigned to a selection of lockers, lockers may have to be restocked several times a day, and the available capacities are stochastic depending on the customers' pickup behavior. In this talk, we discuss basic properties of the resulting decision problem, present a corresponding markov decision process, and provide possible strategies for the problem's solution as well as preliminary numerical results.

3 - Capacitated dial-a-ride problem with drones
Luisa Maier, Markus Hilbert, Andreas Kleine

The importance of convenient and affordable transportation for people with disabilities has grown in recent years. At the same time, online orders and direct deliveries of medical products to customers have increased significantly. To address these challenges, we develop the Capacitated Dial-a-Ride Problem with Drones, CDARPD for short. In this new approach, the vehicles that transport the dial-a-ride customers from a desired starting point to a desired destination are equipped with drones. The drones independently deliver the medical products to the customers. After completing the deliveries, the drone flies back to the vehicle where its battery is swapped to make it completely operable again. Restrictions on the maximum battery capacity of the drones, maximum customer travel times and customer capacities are included. By integrating drone delivery in the dial-a-ride environment, we observe potential benefits in terms of reduced carbon emissions and lower costs. The strength of this novel approach is demonstrated by a computational study.

■ WE-02

Wednesday, 16:30-18:00 - Room: H4

Decomposition Methods & Robust Optimization

Stream: Discrete and Combinatorial Optimization
Invited session
Chair: *Oliver Gaul*

1 - A Branch-and-Cut Approach for Decision-Dependent Robust Optimization Problems

Simon Stevens, Henri Lefebvre, Martin Schmidt, Johannes Thürauf

Compared to classic robust optimization, decision-dependent robust optimization (DDRO) models the uncertainties as being dependent on the decision variables, thus enabling some control over these uncertainties within the model. The literature on DDRO is still limited and most of the existing solution techniques rely on reformulations using duality. Hence, they are naturally restricted to uncertainty sets that can be dualized. Recent results by Goerigk et al. (2025) show that DDRO problems can be reformulated as bilevel optimization problems, opening up new possibilities for solving this class of problems. First numerical results by Lefebvre et al. (2025) indicate that applying general bilevel solvers like MibS to DDRO problems for which the uncertainty set cannot be dualized is possible in general, though not efficient.

We present a tailored branch-and-cut approach for solving DDRO problems in which the uncertainty set is given by an interdicted knapsack problem. To this end, we tailor an interdiction-like cutting plane from the bilevel literature, which is incorporated in the branch-and-cut framework. We present numerical results on a set of benchmark instances and compare our approach with the existing general bilevel solver MibS. The results demonstrate that our approach is significantly faster and capable of solving larger DDRO instances.

2 - Combining Benders Decomposition and Column Generation for Optimal Box Selection

Pia Schreynemackers

We consider a two-stage optimization problem with sparsity constraints, motivated by a common challenge in packaging logistics: minimizing the volume of transported air by optimizing the size and number of available packaging boxes, given the demand for order items. In the first stage, we select the optimal sized packaging boxes. This stage is modeled as a binary selection problem, where the objective function is the value of the subproblem. In the second stage, the items demanded are assigned to the selected boxes. This stage is formulated as an assignment problem, with the goal of minimizing the unused volume in the selected boxes. The objective function in the second stage evaluates the quality of the item-to-box assignment. Additionally, we incorporate sparsity constraints in the first stage, which limit the number of different box types used in the assignment. To solve this problem, we propose a cutting plane approach using Benders Decomposition in combination with Column Generation. In contrast to general Benders cuts, we can understand their meaning here and generate them by a purely combinatorial algorithm. This understanding allows us to apply Column Generation, as the coefficients of the constraints of the new variables also can be derived directly from the combinatorial structure. The combination of both known procedures therefore provides a particularly promising approach to this problem.

3 - A Comprehensive Approach to Solving Large-Scale Security-Constrained Optimal Transmission Switching Problems

Tim Donkiewicz, Oliver Gaul

The Security-Constrained Optimal Transmission Switching problem consists of finding a cost-efficient generator and topology configuration for a power network. Considering the size of the considered networks as well as the large number of scenarios (contingencies) and different topologies, we show how to employ Benders decomposition to solve the problem. We describe acceleration techniques such as partial subproblem solving, cut selection and primal heuristics. Additionally, we present a nested Benders decomposition approach for the problem. Preliminary computational results indicate major performance improvements with the proposed enhancements.

4 - Efficiently Solving Benders Subproblems for the Security-Constrained Optimal Transmission Switching Problem with Substation Reconfiguration

Oliver Gaul, Tim Donkiewicz

The Security-Constrained Optimal Transmission Switching Problem with Substation Reconfiguration deals with the configuration of the topology and generation of a power network in order to reduce overall costs. Security constraints require the individual evaluation of this configuration for a large set of scenarios. Substation reconfiguration allows for a wide variety of possible topologies, but also introduces a significant number of additional edges and nodes. We demonstrate how to tackle the large problem size via a Benders decomposition approach, where the master problem decides on the network configuration, and each subproblem evaluates a security scenario. The main focus of the presentation then lies on an efficient algorithm to fully solve these subproblems by using linear equation systems. In particular, we are able to almost completely remove the computational impact of substation reconfiguration on subproblems. Preliminary results show significant performance gains.

■ WE-03

Wednesday, 16:30-18:00 - Room: H5

District heat and heat networks

Stream: Energy and Sustainability
Invited session
Chair: *Kathrin Fischer*

1 - Integrated Optimization of a Combined Heat and Power Plant with Battery Energy Storage and Photovoltaic Systems

Laura Henke, Jürgen Zimmermann

In recent years, energy costs have risen due to climate change and political crises. Companies with a high energy demand are striving to become more independent from energy suppliers while promoting sustainable energy consumption. Combined heat and power (CHP) plants are more energy-efficient than conventional boilers and power plants. CHPs utilize heat which emerges when power is generated. However, most CHP plants still rely on fossil fuels like natural gas or oil. To improve the environmental impact and reduce energy costs, solar photovoltaics (PV) and battery energy storage (BES) systems could be considered. In Germany, buildings are primarily heated in winter when sunlight is less abundant. During this period, a CHP can be effectively used to meet both heating and electricity demands. In summer, when heating demands are reduced, the PV system generates inexpensive and clean energy. The BES can be charged by the CHP or PV system during times of energy surplus. Any excess energy can also be fed into the public power grid. During periods of less power production, the BES can be discharged, or electricity can be drawn from the grid. A deterministic mixed-integer model has been developed to optimize the operation of the proposed energy system. Operational and emission costs are minimized and the model aims to determine an operational plan for the CHP and BES taking into account the power generation of the PV system and a given energy demand. To identify an optimal operational schedule, hourly data of one year is used. A fix-and-optimize approach has been implemented to achieve an acceptable solution within a short timeframe. Additionally, the impact of various parameters and costs is examined.

2 - An industry perspective on the design of heat exchanger networks

Daniela Gaul, Felix Borgelt, Stephen Braun, Florian Schlosser

Increasing sustainability requirements and rising energy costs are prompting companies to reduce CO2 emissions from process heat. The use of waste heat through heat recovery and heat pumps offers untapped potential for reducing greenhouse gas emissions. However, among other hurdles, a lack of knowledge about optimal integration points is currently preventing the large-scale implementation of waste heat recovery.

The aim of the project HeatTransPlan is to support industrial companies on their way to climate-neutral process heat. To this end, in collaboration with University of Paderborn, OPTANO GmbH provides the decision-making basis for a holistic transformation process using mathematical optimization. We present an industry perspective on the design of optimal heat exchanger networks. After explaining the basic concepts of thermodynamics and heat exchange, we present a mixed-integer linear program, which is solved using a commercial solver. The performance is then enhanced by constraints derived from pinch analysis.

3 - Decarbonizing the Heat Sector Through Joint Optimization of Data Center Locations and District Heating Networks
Lydia Hilarius

As heating constitutes nearly half of total final energy consumption, its decarbonization is imperative to achieve climate neutrality. In urban areas, district heating networks powered by renewable and residual heat sources offer a viable path. At the same time, the rapid expansion of data centers represents a largely untapped opportunity, as their significant excess heat potential could contribute to the decarbonization of heating systems. This study introduces a mixed-integer linear programming (MILP) model that jointly optimizes the allocation of data center capacity, the expansion of the district heating network, and the selection of renewable heat sources for local supply or district heating networks. The objective is to minimize total cost while leveraging synergies between data centers and sustainable heat supply. Heat demand must be met either by district heating, which may include excess heat from co-located data centers, or by local renewable heat sources, such as heat pumps. The model incorporates regionally varying renewable and excess heat capacity and prices, renewable electricity prices, and data center energy efficiency. Finally, a case study is conducted for selected potential district heating areas in Europe based on projected heat demand in 2050. The case study assesses the trade-offs between district heating from renewable sources such as biomass, geothermal, and surface water, alongside excess heat from data centers. Additionally, heat demand can be met by local heat pump solutions. The case study quantifies the role of data centers and illustrates that an integrated planning approach is key to an economically viable and sustainable heat transition.

■ WE-04

Wednesday, 16:30-18:00 - Room: H6

GOR Master Thesis Awards

Stream: PC Stream
Award Competition session
Chair: *Rouven Schur*

1 - Solving the Stochastic Dynamic k-Travelling Repairperson Problem with Deep Reinforcement Learning
Judith Schulze

Efficient real-time dispatch of repair personnel under stochastic, dynamic demand remains a major challenge for service providers. This study addresses the stochastic dynamic k-travelling repairperson problem (SD-kTRP) in a multi-period setting, where service requests arrive over time and must be accepted for same-day service or postponed to the next day. Accepted requests must be inserted into an existing route. The objective is to minimize customer waiting times, which accumulate with each additional stop. Accepting distant or time-consuming requests may delay subsequent services, while postponing them reduces future flexibility. To support anticipative decision-making under uncertain demand, the SD-kTRP is, for the first time, modeled as a sequential decision process. Building on this formulation, a deep reinforcement learning approach is developed that combines deep Q-learning with routing heuristics and is evaluated against two rule-based policies through a numerical study. The proposed approach attains results matching those of the best-performing rule-based policy. An analysis of individual customer waiting times reveals that long service times and peripheral customer locations are primary drivers of delay. These findings underscore the importance of anticipative routing for minimizing waiting times and demonstrate the potential of deep reinforcement learning for real-time decision-making in dynamic environments.

2 - Visualization of Event Graphs for Train Schedules
Samuel Wolf

Software that is used to compute or adjust train schedules is based on so-called event graphs. The vertices of such a graph correspond to events; each event is associated with a point in time, a location, and a train. A train line corresponds to a sequence of events that are associated with the same train. The event graph has a directed edge from an earlier to a later event if they are consecutive along a train line.

We present a way to visualize such graphs. We propose a straight-line drawing of the event graph with the additional constraint that all vertices that belong to the same location lie on the same horizontal line and that the x-coordinate of each vertex is given by its point in time. Hence, it remains to determine the y-coordinates of the locations. A good drawing of a time-space diagram supports users (or software developers) when creating (software for computing) train schedules.

To enhance readability, we define two aesthetic criteria: the number of crossings and the number of turns. We show that minimizing the number of crossings or minimizing the number of turns is NP-hard, and even NP-hard to approximate. To tackle these challenges, we develop exact reduction rules to reduce the instance size. Additionally, we propose exact algorithms, including integer linear programs and parameterized algorithms, along with heuristics for minimizing the number of crossings and the number of turns. Finally, we experimentally evaluate the performance of these algorithms using real-world test data.

3 - Stochastic Online Scheduling on Parallel Machines
Marta Piperno

This work addresses the stochastic online scheduling problem of minimizing the expected total weighted completion time on identical parallel machines. Building on previous research, we analyze the performance of the deterministic algorithm DSOS and the randomized algorithm RSOS. We prove that the DSOS algorithm has performance ratios of 2.309 + 1.309 D, where D is an upper bound on the squared coefficient of variation of the processing times. Notably, this is currently the strongest bound on the performance guarantee of deterministic algorithms for problems with general processing time distributions. Additionally, we establish a performance guarantee of 1.618 + 1.309 D for the DSOS algorithm on a single machine, improving previous results for D lower than 0.764. Furthermore, we derive a deterministic offline variant from the RSOS algorithm that preserves its performance guarantee and improves previous results in the offline setting for D lower than the number of machines. Finally, we conduct a computational study on simulated data to evaluate the performance of the analyzed algorithms in practice.

■ WE-05

Wednesday, 16:30-18:00 - Room: H7

Multiobjective Decision Making with Uncertainty, Risk and Fairness Considerations

Stream: Decision Theory and Multi-criteria Decision Making
Invited session
Chair: *Maximilian Schröer*

1 - Distributed workforce rostering under distance based fairness constraints
Martin Scheffler, Daniel Miodowski, Emilia Dytko

We address a distributed workforce rostering problem arising in the railway construction industry, where both operational efficiency and fairness in workforce allocation are essential. We propose a mixed-integer programming model that integrates typical industry constraints such as worker-task compatibility and location-based dependencies, accounting for workers' travel-distance-related preferences.

Several spatial fairness metrics are analyzed, including (i) total travel distance, (ii) maximum individual travel distance, and (iii) the range between the shortest and longest individual travel distances. These spatial objectives are then combined with classical fairness objectives, particularly the equitable distribution of total working hours among employees over the planning horizon.

We explore the trade-offs between these fairness criteria using Pareto frontiers to provide planners with transparent, data-driven decision support. To reflect the decentralized structure and high volume of concurrent orders in the construction industry, we use real-world data from railway construction projects provided by a German infrastructure company. Our computational results demonstrate that fairness-aware distributed scheduling is not only scalable but can significantly enhance equity among workers without sacrificing overall operational efficiency.

2 - Shifting Power Potentials in changing Organizations: Quantitative Analysis in an entropy-based environment using SPIRIT
Maximilian Schröer, Elmar Reucher
Power constitutes a central yet often overlooked factor in management decision-making research. Particularly within organizational contexts, power not only shapes formal decision-making processes but also influences informal structures, communication flows, and the strategic orientation of firms — all within a dynamic and continuously evolving framework of power relations. Focusing on the theme of power and its transformation, this study examines the impact of hierarchical shifts on the manifestation and redistribution of power. Methodologically, the analysis employs the expert system Shell-SPIRIT, which enables a quantitative assessment of relational power potentials. Through a data-driven, entropy-based modeling of organizational power structures, empirically grounded propositions regarding the strategic management of power dynamics are developed and substantiated. Concrete application examples illustrate the modeling process, and the resulting insights contribute to a deeper understanding of intra-organizational power dynamics, offering new perspectives for the advancement of resilient leadership and decision-making frameworks.

3 - Decision-Making in Idea Management with an Extensive Form Game
Inese Bula
The paper presents novel perspective on idea management by applying game theory concepts. Idea management is a system that helps to generate, develop, and implement ideas. One of the stages of the idea management process is the acceptance and rejection of ideas. This paper looks an application of game theory to idea management, by considering "idea generators" and "idea acceptors" as two players with possible different opinions within an innovation process. The extensive form of the game corresponds to the sequential nature of the idea management process. Taking into account the uncertain payoffs, the model adds realism. The aim of this work is to develop a methodology to deal with uncertainty in idea management, proposing the Nash equilibrium as one of the solutions.

4 - Sustainability-Based Risk Assessment in Complex Systems: A Strength-Influence Framework Using the WINGS Method
Peyman Zandi, Zbigniew Michna
The Decision-Making Trial and Evaluation Laboratory (DEMATEL) method has been widely applied to analyze causal relationships among risks; however, it lacks the ability to incorporate the magnitude of risks within its modeling structure. To address this limitation, this study employs the Weighted Influence Non-linear Gauge System (WINGS) method, which is similar to DEMATEL in analyzing causal relations among system components but also has the ability to integrate the outputs of various risk assessment methods as model inputs. This feature enables the simultaneous analysis of both risk strength and risk interactions, offering a comprehensive approach referred to as "strength-influence risk analysis" within complex systems. Accordingly, this paper proposes a novel hybrid model for assessing operational risks by considering their interactions and overall effects on sustainability. First, the weights of sustainability-related risk assessment criteria are determined using fuzzy Shannon entropy, and the intensity of each risk is calculated as fuzzy numbers. Then, the defuzzified risk scores, along with the interrelations among risks, are fed into the WINGS model for final analysis. The proposed model is applied to operational risk management in a gas refinery, where the results demonstrate its effectiveness in assessing the impacts of risks on various aspects of sustainability, while accounting for cause-effect risk relationships.

■ WE-06
Wednesday, 16:30-18:00 - Room: H9

Predictive Analytics: Forecasting II

Stream: Analytics, Data Science, and Forecasting
Invited session
Chair: *Sven F. Crone*
Chair: *Ralph Grothmann*

1 - Feature selection for Neural Network Forecasting - an empirical evaluation of partial dependence, pertubation and gradient techniques for railway revenue forecasting
Sven F. Crone

Feature selection is considered of preeminent importance for specifying accurate, robust and efficient machine learning methods, attracting over 22,000 academicspapers. While some prominent methods include feature selection in their methodology, such as decision tree-based methods of xgboost, others inlcuding neural networks (NN) leave feature selection to the modeller. For time series data, most papers employ simple heuristics such as p= n*s autoregressive lags yt-p, with s = seasonal length, and n typically set between 1 and 3 (e.g. nnetar, Hyndman and Caceres, 2024). Crone and Kourentzes (2010) propose established statistical techniques, such as ACF, PACF, and stepwise regression for NN feature selection. Zimmermann et al. (2020) suggest to unfold partial dependence plots across time series and check importance, consistency and nonlinearity. More recent methods determine feature importance based on the predictive performance of the output, including pertubation baeed feature importance applicable across ML methods, and gradient based feature importance utilising the learning information of neural networks during parameterisation. However, despite their prominence in classification, clustering and regression research, only few papers consider these feature selection methods on time series data for forecasting. This paper seeks to address this gap by comparing statistical approaches, heuristics and three ML feature selection approaches pertubation, partial dependence and gradient weight based approaches on the empirical accuracy for a real world railway demand dataset with many features. The results indicate the promise of more advanced approaches of feature importance over simpler methods, and suggest computationally efficient trade-offs between accuracy and speed.

2 - Model Building and Forecasting with Recurrent Neural Networks
Hans Georg Zimmermann, Nico Beck, Julian Stengl

Time series modeling is often seen as a process in which one starts with a data set, identifying features of the data (e.g. periodicity) and go on to the model building. In this talk we want to follow another guideline: First, think about a reasonable mathematical frame for your modelling. Here we will insist not only on universal approximation but will work out the specifics of Historical Consistent Neural Networks. Second, ensure that the chosen model class can be adapted in a best possible way to observations (Typically, in this frame we must work with overparameterized models). Third, think about the relevant observations for your modelling. Without step one and two it is irrelevant to discuss the importance of data (a crazy counterexample would be: if you believe in linear models than the best model of a sinus wave would be the x axis). Thus, the mathematical frame and its handling has to be done before you focus on the data. Finally one has to discuss the uncertainty of the forecast including concepts for this uncertainty and their representation.

■ WE-07
Wednesday, 16:30-18:00 - Room: U2-205

Simulation, Data & Decision Support

Stream: Simulation and Quantum Computing
Invited session
Chair: *Max Krueger*

1 - Reassessing Validation & Verification in AI-Driven Modeling and Simulation
Dominic Weller

The German Armed Forces regularly conduct scientific studies in the field of analytical and constructive modelling and simulation (M&S) to support decision-making and capability planning. Artificial Intelligence (AI), particularly machine learning (ML), is becoming an integral part of these projects. However, due to partly insufficient results from previous studies and the rapid development of AI, questions arose if existing verification and validation (V&V) approaches and established M&S processes are still adequate.

Therefore, we conducted a comprehensive internal study to find answers regarding these concerns. This included 1. a meta-analysis of previous studies and thereby identifying recurring challenges and lessons learned, 2. a systematic analysis of the current state of research and an intensive exchange on the topic with industry partners, NATO experts, and academic institutions, 3. the contextualization and definition of the problems related to the use of ML and AI within the M&S context, therefore providing a practitioners perspective and 4. the transfer of the findings to our guidelines, procedures, and processes to identify areas for action and to suggest best practices.

The results show that most of the identified problems often have a basic character and not necessarily originate from the application of AI itself. We must apply current M&S and V&V methods consistently and a deeper understanding of AI/ML technologies must be established. Only when the basic prerequisites of M&S are met, advanced methods such as Explainable AI (XAI) and corresponding frameworks may contribute to supporting certain steps in the simulation process.

2 - Parameterization Support of Bayesian Networks Using a Large Language Model

Max Krueger

In recent decades, Bayesian Networks have been used in a variety of applications, particularly for classification problems. When building Bayesian Networks, in addition to creating a suitable qualitative structure, i.e., a Directed Acyclic Graph (DAG), a quantitative parameterization of the conditional probabilities must also be conducted for all nodes. Each node of the DAG represents an aspect of the application as a random variable. If no training data is available for parameter estimation when using learning methods for Bayesian Networks, subject matter experts are usually consulted to estimate the required conditional probabilities based on their application knowledge. The idea behind this contribution is to replace the support of these application experts, who may be challenging to find. The parameterization of Bayesian Networks is then condcuted by application of a large language model. We describe a possible approach in which the necessary parameters of the Bayesian network classifier are to be determined for an example application from air surveillance with the help of the LLM-based chatbot ChatGPT. Finally, the resulting parameterization of the Bayesian Network generated in this way is compared with a classification network generated by subject matter experts with regard to its classification performance.

3 - Ordinal Cascades of Linear Classifiers

Ludwig Maximilian Lausser

Ordinal classifier cascades (OCCs) are specialized multi-class classifier systems (MCCS) designed to detect ordinal relations among classes. They can be applied in de novo analyses of large class collections, where they systematically evaluate all potential ordinal (sub-)cascades [1]. For example, they can be utilized to reconstruct developmental processes from gene expression profiles, making them valuable tools in ontogenesis and oncogenesis [2].

However, the performance of ordinal classifier cascades is highly dependent on the selected type of base classifier. Underlying ordinal relations may only be detected if the correct type of base classifier is chosen. In a previous study, linear classifiers outperformed their non-linear counterparts.

In this work, the influence of training algorithms of the base classifiers will be analyzed. In an empirical study, ordinal classifier cascades are coupled with different types of linear classifiers, and the influence on their decision regions is analyzed. The ordinal classifier cascades will be compared based on their generalization performance and their ability to detect ordinal relations among classes.

1. Lausser L, Schäfer LM, Kühlwein SD, Kestler AMR, Kestler HA. Detecting Ordinal Subcascades. Neural Processing Letters, 52(3): 2583-2605, 2020. 2. Lausser L, Schäfer LM, Schirra LR, Szekely R, Schmid F, Kestler HA. Assessing phenotype order in molecular data. Scientific Reports 9(11746), 2019.

■ WE-08

Wednesday, 16:30-18:00 - Room: H8

Risk Management in Healthcare

Stream: Health Care Management
Invited session
Chair: *Christina Bartenschlager*

1 - Simulating and assessing the progression of cyberattacks through hospitals

Abhilasha Bakre

Digital technologies are being increasingly adopted in hospitals, rendering them vulnerable to cyberattacks. Recent examples can be found of blocked computer systems, breached intranets and theft of patient data. Their consequences include forcing staff back to offline processes, cancellation of numerous appointments, transferring patients to other hospitals, surgery delays and closing emergency rooms. Additionally, hospitals need to communicate with each other for sharing clinical data, electronic health record, patient management platforms and diagnostic services. An affected hospital could hence act as a vector for a cyberattack to spread to others, causing cascading effects within a healthcare network, shutting down multiple units and disrupting systems. In order to better understand the sequential disruption in clinical services, this study takes a holistic approach by constructing a patient- and data-sharing network to identify the connections between hospitals. The proposed model captures the heterogeneous and inconsistent information security landscape of a hospital, accounting for the complex interrelated structures. An agent-based simulation facilitates analysis of the spread of cyberattacks among various hospitals, in turn providing insights for decision support aimed at ensuring an entire multi-hospital network is more capable of preparing for, responding to and recovering quickly from such attacks in the future.

2 - Mitigating Risks in Critical Care with Analytics

Jingui Xie, Zhiyuan Lou

Deciding when to stop medical treatment with uncertain outcomes and predictions is a critical challenge in intensive care units. This research develops a risk-sensitive approach to optimal medical stopping decisions by integrating outcome variability into the decision-making process and incorporating predictive information about the next state. We model the problem using a risk-sensitive Markov decision process with an entropic risk measure to capture decision risk. Our analysis reveals that under some assumptions the optimal policy follows a threshold-based structure, with a submodular value function and a risk-aware decision framework. We identify three distinct risk-sensitive strategies that diverge from the nominal stopping problem: an aggressive policy under deterministic terminal costs, a conservative policy, and a mixed strategy that transitions from conservative to aggressive actions. To evaluate the effectiveness of our model, we conduct numerical experiments on two critical decision cases: extubation and discharge. Our results demonstrate that the proposed approach achieves a more favorable balance between expected costs and risk exposure—where a slight increase in expected cost can lead to a substantial reduction in risk. These findings underscore the inherent trade-off between the immediate risks of stopping treatment and the ongoing risks of continued treatment. By leveraging our model, healthcare managers can significantly mitigate downside risk with a minimal increase in expected costs, enhancing decision-making in high-stakes clinical settings.

3 - Integrated Machine Learning-based patient clustering and prediction as a tool to improve decision-making in ICU resource utilization

Christina Bartenschlager

Maintaining high-quality patient care while managing scarce resources is a constant challenge for the management of intensive care units. Thanks to its data-rich nature, on the one hand, critical care is in a prime position to receive innovative decision support by means of Machine Learning. On the other hand, in literature either traditional supervised or unsupervised Machine Learning techniques are trained based on the American MIMIC intensive care unit data set. In this work, we research the application of an integrated supervised and unsupervised Machine Learning approach, called Cluster-then-predict, to a MIMIC-equivalent real-world intensive care unit dataset of a German University Hospital. The ultimate goal is to improve decision-making in intensive care unit resource utilization based on integrated clustering and prediction of a common denominator for resource use, the length of stay of a patient.

■ WE-09

Wednesday, 16:30-18:00 - Room: H15

Modelling and APIs

Stream: Software for Operations Research
Invited session
Chair: *Susanne Heipcke*

1 - Timefold: the open source solver for software engineers

Geoffrey De Smet

Most optimization solvers require the business constraints and objectives as math equations. Timefold Solver is different. It's an open source solver that accepts them as plain Java or Python code. That means the constraints can reuse existing code, such as date and time libraries and don't face any linear or quadratic limitations.

In this session, I'll explain the basics, demonstrate a vehicle routing implementation and live code a school timetabling model.

2 - Embedding Neural Networks into Optimization Models with GAMSPy

Frederik Fiand, Michael Bussieck, Hamdi Burak Usul

GAMSPy is a powerful mathematical optimization package which integrates Python's flexibility with GAMS's modeling performance. Python features many widely used packages to specify, train, and use machine learning (ML) models like neural networks. GAMSPy bridges the gap between ML and conventional mathematical modeling by providing helper classes for many commonly used neural network layer formulations and activation functions. These allow a compact description of the network architecture that gets automatically reformulated into model expressions for the GAMSPy model.

In this talk, we demonstrate how GAMSPy can seamlessly embed a pretrained neural network into an optimization model. We also explore the utility of GAMSPy's automated reformulations for neural networks in various applications, such as adversarial input generation, model verification, customized training, and leveraging predictive capabilities within optimization models.

3 - Recent new features of FICO Xpress APIs and Xpress Mosel

Susanne Heipcke

This talk gives an overview of recent updates to the FICO Xpress APIs: a completely new set of object-oriented APIs (C++, C#, Java) has been published that make use of modern programming language features. These APIs work directly with Xpress Solver without any need for keeping intermediate copies of problem data.

The Python API for Xpress has been reworked to align it more closely with the other APIs, in particular by introducing linked objects that directly modify the problem, leading to performance improvements for large problems. Besides NumPy, the Python API now also supports SciPy for the efficient creation of large constraint expressions.

We shall also give a short introduction to the newly published Julia API for Xpress that is provided open-source on Github (see https://github.com/fico-xpress/XpressAPI.jl) and through the official Julia registry.

FICO Xpress Mosel has undergone some restructuring of its distribution and build processes, with significant updates to its open source component 'moseltest' (see https://github.com/fico-xpress/mosel). Other new Mosel features include improvements to data handling functionality and support of new Xpress features.

4 - Writing and solving models with the new FICO Xpress C++ API

Daniel Junglas

Starting with version 9.4 FICO Xpress introduced new APIs for object oriented programming languages (Java, .NET). This was finished with the C++ API in the latest release The new APIs are designed as an object-based layer ensuring a memory-efficient and reliable experience to the user. With the new API, the use of features such as callbacks becomes easier, and it gives access to the full set of problem types available with Xpress.

Among the key features of the new Xpress API are the ability to use modern programming concepts such as lambdas, templates, STL containers etc.

We will present the new C++ API, show different ways of building models with it, compare model building time in the new APIs against a direct C implementation, and present a showcase that used the API to solve a real world problem.

■ WE-10

Wednesday, 16:30-18:00 - Room: H16

Flow Lines and Fairness Considerations

Stream: Supply Chain Management and Production
Invited session
Chair: *Andreas Kloos*

1 - Integrating Worker Preferences in Disassembly Line Balancing

Christian Weckenborg, Judith Schulze, Kerstin Schmidt, Thomas Spengler

Product and material recovery requires systematically dismantling products to enable parts reuse and recycling. The most efficient way to achieve this is by establishing a disassembly line. However, disassembly tasks vary widely, ranging from physically demanding operations to tasks requiring precision and patience. Assigning tasks to workers without considering their individual preferences may lead to dissatisfaction due to perceived unfairness in task allocation. At the same time, a disassembly line must be economically viable, making it necessary to explore the interplay between preference fulfillment and profitability. However, the integration of profit maximization and the fulfillment of workers' preferences from an equity perspective has not yet been studied in disassembly line balancing. This paper proposes a multi-objective mixed-integer linear program that determines the number of workstations, defines the disassembly depth, and assigns workers to tasks and stations. The problem is solved using a lexicographic approach that prioritizes profit maximization, with worker preference fulfillment as the secondary objective. Results from exemplary instances show workers' preferences can be adequately considered at a low loss of profit.

2 - Workforce Planning Under Seniority Rules And Fairness Conditions

Guangrui Yang, Rainer Kolisch

We are considering a medium-term workforce planning problem with a planning horizon of 36 months. The workforce consists of two classes, with 18 and 23 levels, respectively. In each class, workers automatically progress to the next level after one year. Regardless of their level, the workforce must cover the demand for class one and class two workers using regular time and overtime. The planning problem involves making dynamic decisions about the size and composition of the workforce in order to minimize labor costs. For each month, it has to be determined how many workers are hired at the lowest level of class one, and how many class one workers are promoted to class two. Thereby, seniority rules and fairness conditions must be respected. We model the problem as a mixed-integer program, which can be solved with Gurobi. We present a case study from an airline and the results of a computational study.

3 - Linearizing Convolutional Neural Networks for Performance Evaluation and Optimization of Stochastic Flow Lines

Andreas Kloos, Justus Arne Schwarz

Simulation is widely used for evaluating stochastic manufacturing systems, due to its adaptable modelling capacities and the absence of exact or even approximate analytical solutions. Solving decision problems with integrated simulation models can be time-consuming, due to the need for many replications and the combinatorial nature of many problems. To increase the speed of the evaluation of the performance measures of a manufacturing system, the existing literature suggests replacing simulation with Artificial Neural Networks pretrained with simulation results. We train a Convolutional Neural Network (CNN) with flowline feature data to predict the throughput of a flowline configuration. We then solve optimization problems, by linearizing the trained CNN, thereby transforming the non-linear problem into a mixed-integer linear problem (MILP), which is tractable by standard solvers. Furthermore, the impacts of different sampling methods for generating training data and regularization methods are investigated.

4 - Optimization-Based Feed Logistics and Silo Management for Sustainable Livestock Farming
Xiaoyi Gu, Dennis Bode, Jan-Hendrik Ohlendorf

Efficient feed logistics and silo management represent essential elements of sustainable livestock farming and modern agricultural supply chain systems. This study proposes a Mixed-Integer Linear Programming (MILP)-based optimization model designed to automate decision-making processes in feed supply chains. By incorporating real-time data from farm management systems, the model generates optimized delivery schedules aimed at minimizing transportation inefficiencies while maintaining continuous feed availability. The formulation accounts for critical operational constraints, including the maintenance of predefined silo buffer levels, adherence to feed sequencing requirements, optimal utilization of truck compartments, and preparations for aligning production activities with off-peak energy periods. To support practical implementation, a web-based decision-support system is developed, offering interactive visualizations and real-time planning functionalities. Results from initial pilot customers indicate that using the proposed method for automatic ordering achieves slightly better truck load efficiency compared to manual ordering. This improvement can help reduce transportation costs, enhance feed distribution efficiency, and lower energy consumption.These findings underscore the relevance of operations research methodologies in advancing the efficiency, sustainability, and resilience of agricultural production and supply chain management.

■ WE-11

Wednesday, 16:30-18:00 - Room: U2-200

Heuristics

Stream: Heuristics, Metaheuristics and Matheuristics
Invited session
Chair: *Andreas Fink*

1 - Optimizing Ocean Waste Collection through a Team Orienteering Problem with Moving Targets
Paulina Heine

Plastic waste pollution in the oceans presents growing environmental and logistical challenges. Floating debris accumulates in large regions such as the Great Pacific Garbage Patch. Despite its name, this "patch" is not a continuous area of waste, but rather a vast zone where plastic debris concentrates into multiple dynamic hotspots driven by ocean currents. This research addresses the problem of coordinating waste collection vessels in such a highly dynamic environment, enabling them to move from hotspot to hotspot to collect as much waste as possible. This task is modeled as a Team Orienteering Problem with Moving Targets, where both hotspots and vessels are affected by current direction and strength.

The objective is to maximize waste collection within a fixed time window. To reduce the complexity of the problem, it is first modeled as a static version, disregarding current-induced dynamics. This simplified version is solved exactly and then evaluated under realistic conditions by deploying it in a dynamic simulation that includes the actual influence of ocean currents. The static solution is benchmarked against a reactive greedy heuristic, which continuously reallocates patches in real time based on the distance between vessels and patches or the value of a hotspot.

The distribution, location, and movement of debris hotspots are simulated using real ocean current data. The plastic debris itself is artificially introduced to generate controlled yet realistic collection scenarios.

This work contributes to the field by extending the orienteering problem to current-driven maritime environments, integrating movement-aware routing and dynamic hotspot allocation. The approach supports the development of effective strategies for marine waste management.

2 - A heuristic for two-stage mixed-binary stochastic programming problems based on scenario decomposition and machine learning techniques
Jonas Wendisch, Achim Koberstein, Kevin Tierney

We consider the scenario decomposition method for two-stage mixed-binary stochastic programming problems first introduced by Ahmed in 2013. This algorithm systematically evaluates and cuts off first-stage candidate solutions obtained from scenario subproblems. We turn this method into a heuristic by using classification and ranking techniques to reduce the set of candidate first-stage solutions. We evaluate different variants emerging from this heuristic framework on the well-known stochastic server location (sslp) problem instances.

3 - Deep Representation Learning for Generating Candidate Solutions in Multi-Agent Negotiation Evolutionary Search
Andreas Fink, Jörg Homberger

We address multi-agent decision-making problems that require the identification of mutually beneficial agreements within formally defined solution spaces. A typical application is the coordination of delivery sequences or machine schedules among autonomous companies in a supply chain. We propose a novel autoencoder-based method for generating candidate solutions in an evolutionary search negotiation framework. In this approach, candidate solutions are constructed iteratively through recombinations in the latent space, guided by the encoder-decoder structure of the trained autoencoder network. We examine the effect of different configurations for application scenarios and demonstrate the potential of the approach to improve solution quality and negotiation efficiency.

■ WE-12

Wednesday, 16:30-18:00 - Room: H10

AI in Optimization Heuristics

Stream: Artificial Intelligence, Machine Learning and Optimization
Invited session
Chair: *Roberto Battiti*

1 - Intelligent Optimization: explorations in using Reinforcement Learning for the Online Tuning of Optimization Heuristics
Roberto Battiti, Mauro Brunato

Reactive Search Optimization (RSO) [1] advocates the integration of sub-symbolic machine learning techniques into search heuristics. The word reactive hints at a ready response to events during the search through an internal online feedback loop for the self-tuning of critical parameters. In this manner the knowledge about the specific task and the local properties of the fitness surface surrounding the current tentative solution can influence the future search steps to render them more effective. Reinforcement Learning (RL) arises in a different context of machine learning, in which feedback signals from the environment are used by the learner to modify future actions.

This paper is about Reinforcement Learning (RL) applied to online parameter tuning in Stochastic Local Search (SLS) methods for Combinatorial Optimization.

Our initial investigation about using RL for Optimization [2] considered RL for the Reactive Tabu Search (RTS) method, where the appropriate amount of diversification in prohibition-based (Tabu) local search is adapted in a fast online manner to the characteristics of a task and of the local configuration.

The topic of (deep) Reinforcement Learning for Optimization is witnessing an intense research effort in recent years. In this work we compare the novel and old approaches on significant Combinatorial Optimization tasks to assess their strengths and weaknesses.

[1] The Reactive Tabu Search Roberto Battiti, Giampietro Tecchiolli ORSA Journal on Computing 1994/5 Volume 6 (2) Pages 126-140

[2] Learning while Optimizing an Unknown Fitness Surface. Roberto Battiti, Mauro Brunato, Paolo Campigotto. Proc. 2nd Learning and Intelligent Optimization Workshop (LION2007 II, Trento, Italy, 2008

2 - Stochastic first-order methods can leverage arbitrarily higher-order smoothness for acceleration
Chuan He

In many emerging applications—particularly in machine learning and related fields—optimization problems are often large- or even huge-scale, which poses significant challenges to classical first-order methods due to the high cost of computing the exact derivative. To address this issue, stochastic first-order methods (SFOMs) have been extensively studied, as they employ stochastic estimators of the gradient that are typically much cheaper to compute.

In this work, we propose an SFOM with multi-extrapolated momentum for nonconvex unconstrained optimization, where multiple extrapolations are performed in each iteration, followed by a momentum update based on these extrapolations. We show that the proposed SFOM can accelerate optimization by exploiting the higher-order smoothness of the objective function. To the best of our knowledge, this is the first SFOM to leverage the Lipschitz continuity of arbitrarily higher-order derivatives of the objective function for acceleration. Preliminary numerical experiments validate the practical performance of our method and support our theoretical results.

3 - Effective Large Neighborhood Search for Flexible Job Scheduling via Neural Deconstruction

Davide Zago, André Hottung, Fynn Martin Gilbert, Rossella Cancelliere, Kevin Tierney

End-to-end machine learning has provided impressive results on several combinatorial problems, consistently shrinking the gap with traditional approaches used in operations research, and showing potential applicability in the industrial world. Meanwhile, there has been an increasing number of learning metaheuristics with successful applications to different domains. In particular, neural deconstruction in large neighborhood search recently came out as the first machine learning approach to surpass traditional methods on routing problems. In this work, we apply the rationale behind this technique to two largely addressed scheduling tasks, i.e. standard and flexible job-shop problems. To account for alternative assignments of operations to machines, we propose a novel extension of the well-known disjunctive graph representation. Our trained models outperform end-to-end and search-based methods and closely match traditional approaches, needing limited domain-specific knowledge. Our results enforce the effectiveness of neural deconstruction search, and demonstrate its potential to a wider range of combinatorial problems.

Thursday, 8:45-10:15

■ TA-01

Thursday, 8:45-10:15 - Room: Audimax

Routing, transportation, and scheduling

Stream: Mobility, Transportation, and Traffic
Invited session
Chair: *Jonas Witt*

1 - A two-stage model for periodic timetabling with fixed line activities
Niels Lindner, Christian Liebchen

The timetable is a central pillar of any public transportation system. Constructing and optimizing periodic timetables in terms of passenger comfort and operational efficiency does not only lead to NP-hard optimization problems, but is also computationally challenging in practical applications. The Periodic Event Scheduling Problem (PESP) as standard mathematical tool benefits from its succinct formulation and rich combinatorial structure, but suffers from poor linear programming relaxations and weak dual bounds.

These difficulties persist in a reduced version, where driving and dwelling activities of the lines are assumed to be fixed. In this case, fixing the initial departure time of each line fully determines the timetable, and for each pair of lines, the resulting (weighted) transfer or headway duration can be expressed in terms of a piecewise linear non-convex function in terms of the difference of the initial times. When the number of activities between two lines is bounded, this function can be computed in polynomial time.

By precomputing these piecewise linear functions, and inserting them into a mixed-integer program with the initial departure times as variables, we introduce a new, yet equivalent, formulation for reduced periodic timetable optimization problems. The model bears analogies with quadratic semi-assignment approaches, but is more compact, and offers alternative ways to compute primal and dual bounds. We evaluate the computational behavior of our approach on realistic benchmarking instances.

2 - Inspector Scheduling for German Road Inspection
Patricia Ebert, Thomas Schlechte, Stephan Schwartz

Every year, over 500,000 truck and bus inspections are carried out by road inspection services of the German Federal Logistics and Mobility Office (BALM). The controls are performed by teams of inspectors and can be mobile (traversing the road network) or stationary (e.g., at certain service areas). Furthermore, a number of control topics must be assigned to a duty in order to specify the focus of the control and to achieve the road inspection control targets of the BALM. We present a model to solve the respective duty scheduling and crew rostering problem in order to obtain duty rosters that comply with numerous legal regulations while maximizing the 'control success' in order to achieve the control targets. Extending an existing model for the scheduling of toll enforcement inspectors, we formulate the Template Assignment Problem (TAP), where feasible combinations of control topics (called templates) are assigned to the duties from the basic model. The TAP is modeled as a mixed-integer linear program on a directed hypergraph. The hyperarc approach allows us to easily model interdependencies between single assignments. For instance, certain combinations of control topics are particularly desired or undesired to be processed in parallel within a single control. Moreover, many constraints regarding inspector's qualifications and the allocation of control topics can be satisfied during the construction of duty templates and hyperarcs. This allows to reduce the complexity of the final optimization problem. Since our approach is used in production by BALM to create the inspectors' duty rosters, we prove the effectiveness of our model on a number of real-world instances.

3 - A Journey Through DHL's Routing Use Cases
Jonas Witt, Martin Comis, Milena Tyra

Efficient routing is essential for optimizing logistics operations to reduce emissions and minimize costs. While off-the-shelf software solutions offer substantial capabilities, our practical experience at DHL reveals specific requirements that these tools often cannot address. Based on real use cases, we present unique challenges such as park-and-loop in last mile mail delivery, the extraction of courier knowledge from past tours for last mile parcel delivery, as well as routing with consolidation options in pickup-and-delivery operations for bundled shipments. Our insights emphasize the need for tailored solutions to effectively manage the largest logistics network in Germany, ensuring operational efficiency and improved service delivery.

■ TA-02

Thursday, 8:45-10:15 - Room: H4

Combinatorial Optimization

Stream: Discrete and Combinatorial Optimization
Invited session
Chair: *Sven Krumke*

1 - On a Generalization of the Maximum Weighted Independent Set Problem
Hannah Borgmann, Sven Krumke, Luis Paquete

Given a connected undirected graph G with node weights and a family F of connected subgraphs of G, we study the problem of choosing a subset of nodes of G that maximizes the total weight whilst only containing a limited number of nodes from each given subgraph from F. We call this problem maxFSG. MaxFSG is a generalization of the well-known Maximum Weight Independent Set Problem (in this case F is the set of all subgraphs induced by edges of G) and, hence, NP-hard in general. To the best of our knowledge, maxFSG has not been investigated before. We study some possible restrictions on the structure of G and on the family of subsets F and determine whether they are sufficient to make maxFSG solvable in polynomial time on those instances or whether the problem remains NP-hard. In particular, we show NP-hardness of maxFSG on trees and provide a polynomial algorithm for instances in which G is of bounded treewidth and F of bounded node-frequency.

2 - Polynomially Solvable Cases of the Quadratic Binary Optimization Problem with a Fixed Cardinality Constraint
Thi Thanh Tu Le, Thorsten Koch

Quadratic unconstrained binary optimization (QUBO) problems and one of their variants, the quadratic binary program with a fixed cardinality constraint, are both well-known NP-hard problems. In some cases, QUBOs can be solved in polynomial time due to special structural properties of the cost matrix; however, this tractability no longer holds when a fixed cardinality constraint is imposed. We explore structural conditions on the cost matrix that lead to polynomial-time solvability of the quadratic binary optimization problem with a fixed cardinality constraint.

3 - Investment Guarantees for Inner Approximations
Sven de Vries, Stephen Raach, Rakesh V. Vohra

Akbarpour, Kominers, Li, Li, and Milgrom [2023] provided a characterization for when an incentive-compatible approximate mechanism's worst-case allocative and investment guarantees coincide. The characterization, however, fails in some natural settings, such as multi-unit demand with linear utilities. In this case we pro- pose an inner approximation framework that yields an incentive-compatible greedy mechanism whose allocative and investment guarantees coincide.

4 - On the Complexity of Graph-Theoretic Versions of Partial Scenario Set Cover
Shai Dimant, Sven Krumke

The Partial Scenario Set Cover problem (PSSC) is a known generalization of the (partial) set cover problem. We are given a finite ground set Q, a collection S of subsets of Q with associated nonnegative costs, and a second collection U of subsets of Q. The goal is to select a minimum-cost sub-collection of S that covers at least l sets from U.

The Smallest k-Edge Subgraph Problem (S-k-ES) is a special case of the PSSC in which the scenarios are given by single edges and the nodes play the role of the sets. The S-k-ES can be solved in polynomial time on graphs of bounded treewidth. This raises the question of whether graph-theoretic versions of PSSC can be solved in polynomial time on treewidth bounded graphs as well.

We first consider a generalization of the classical Steiner Tree problem, where given a graph G = (V,E), a non-negative cost function c on E and a subset R of vertices, the goal is to find a minimum cost subtree of G containing all terminal nodes, i.e. all nodes from R. In our problem, called Partial Scenario Steiner Tree (PSST), the terminal set R is uncertain: One is given a collection U of (terminal set) scenarios and the goal is to find a minimum cost subtree of G which completely contains at least a prespecified number l of the scenarios from U. The PSST is again a graph-theoretic special case of the PSSC. We show that while PSST is trivial on path graphs and can be solved in polynomial time on trees when U is a subset of edges, it becomes NP-hard already on star graphs when this assumption is dropped, even when all scenarios are still of size 2. We identify a class of complicating scenarios whose number if constant, makes the problem polynomial time solvable. We then generalize our results to other graph-theoretic versions of PSSC.

■ TA-03

Thursday, 8:45-10:15 - Room: H5

Intralogistics

Stream: Project Management and Scheduling
Invited session
Chair: *Lara Nehrke*

1 - Order consolidation in warehouses: The loop sorter scheduling problem

Stefan Schwerdfeger, Nils Boysen, Konrad Stephan

To meet today's ambitious order throughput targets, many distribution centers, especially those operated by online retailers, apply batching and zoning in their picker-to-parts warehouses. These order retrieval policies improve the pick density per tour by unifying multiple customer orders to larger pick lists and allow a parallelization of the picking process among multiple zones, respectively. The price for this is an additional consolidation stage, where picked products must be sorted according to customer orders, typically with the help of a sortation conveyor. In this context, we treat the loop sorter scheduling problem, which is defined as follows. Once a wave of orders, picked concurrently in multiple zones, has been inducted onto a closed-loop sorter, we have to assign the products that refer to the same stock keeping units (SKUs) to orders and orders to packing lanes, where they are prepared for shipping. Furthermore, we have to decide on the sequence in which the orders are channeled into their packing lanes. Our aim is to minimize the makespan until all orders of the current wave are readily sorted.

2 - Collaborative Routing Problems in Automated Warehouses

Lara Nehrke, Julian Golak, Dominik Kress, Malte Fliedner

The pick-and-drive system is an innovative approach to warehouse automation for order picking, combining two types of autonomous mobile robots (AMRs). Storage and supply AMRs (S-AMRs) transport unit loads from a storage area to a disposition area, where picking AMRs (P-AMRs) move freely to retrieve items using robotic arms. We take an operational perspective within this setting and address the problem of determining meeting locations and sequences for the AMRs to ensure efficient fulfillment of all customer orders. To do so, we interpret the problem as a vehicle routing problem with collaboration under different objectives, namely the minimization of either the total distance traveled by the AMRs or the sum of the completion times of customer orders. We develop mathematical models and derive structural properties. Furthermore, we present different solution methods based on these insights. In a comprehensive numerical study, we compare the modeling approaches and the solution methods. All methods are evaluated to assess their performance and applicability in practice.

■ TA-04

Thursday, 8:45-10:15 - Room: H6

Optimality Conditions and Optimal Control

Stream: Continuous and Global Optimization
Invited session
Chair: *Gustav Feichtinger*

1 - New perspectives on invexity and its algorithmic applications

Ksenia Bestuzheva

One of the key properties of convex problems is that every stationary point is a global optimum, and nonlinear programming algorithms that converge to local optima are thus guaranteed to find the global optimum. However, some nonconvex problems possess the same property. This observation has motivated research into generalizations of convexity. This talk proposes a new generalization which we refer to as optima-invexity: the property that only one connected set of optimal solutions exists. We state conditions for optima-invexity of unconstrained problems and discuss structures that are promising for practical use, and outline algorithmic applications of these structures.

2 - Invariance conditions for a class of set-valued dynamic systems and applications

Sigifredo Laengle, Tomás Laengle Aliaga

One of the fundamental problems in viability theory is determining the initial states of a dynamic system for which at all solution evolutions remain confined within a prescribed constraint set (the invariance problem). This problem is highly relevant to real-world applications, particularly management and control, where high-dimensional dynamical models frequently represent such systems. To solve those practical problems, the extant literature documents substantial challenges when dealing with systems of dimension greater than four, except in affine and convex problems with bounded norms. In response to this limitation, we comprehensively examined current approaches and proposed conditions for a class of set-valued operators. Nonetheless, as many dynamical systems fail to satisfy our conditions, a critical direction for future work involves extending this framework to encompass more general classes of systems.

3 - Stationary-through-immigration Populations: Optimization beyond Pivot Points

Andreas Novak, Thomas Fent, Stefan Wrzaczek, Gustav Feichtinger

Starting point are stationary-through-immigration (SI) populations (Espenshade, Bouvier, and Arthur 1982), which are achieved by replenishing stable but shrinking populations with a constant influx of migrants. As a first step the optimal entry age maximising the support ratio in order to identify a new decisive threshold of demographic change is calculated.

We derive analytical conditions under which two local maxima of the support ratio exist. As demographic change progresses, a level is reached at which the global maximum jumps from the local maximum at higher ages to the local maximum at lower ages. We interpret this as the pivot point separating two regimes of demographic change. This threshold marks a significant change in population dynamics and we can quantify at any time whether this threshold has already been surpassed.

In a next step the model is extended to an age-structured OC-problem where the dynamics of the population is governed by the McKendrick von Foerster equation including a jump at a certain age due to immigration which acts as control variable.

4 - Optimal control of cartel violence: Multiple equilibria, narrow corridors, and weak Skiba curves

Gustav Feichtinger, Jonathan Caulkins, Gian Maria Campedelli, Dieter Grass, Rafael Prieto-Curiel, Gernot Tragler, Stefan Wrzaczek

We present an optimal control model for evaluating how Mexico might best use two instruments (security measures and social programs) to control a pair of criminal cartels that are in lethal conflict with each other. For our model and parameters being made as realistic as possible, our analysis is meant to provide guidance to the Mexican government. In this presentation we will mostly focus on variations on our model and parameters that reveal interesting structural features, because we believe that the basic architecture of our model is intrinsically interesting to the optimal control community - both with respect to the structure of the solutions and their economic interpretation. Our results are derived with the help of bifurcation analyses and include solutions with as many as ten equilibria, some separated by Skiba curves. A highlight of our analysis is the existence of triple Skiba points as well as of 'narrow corridors'. Since the pathbreaking work of the nobel price winners Acemoglu and Robinson, the occurrence of the latter admit interesting insights into the economic behavior of pertinent processes.

■ TA-05

Thursday, 8:45-10:15 - Room: H7

Multiobjective Optimization 1: Non-standard Dominance Cones

Stream: Decision Theory and Multi-criteria Decision Making
Invited session
Chair: *Mara Schubert*

1 - Axiomatic Foundations and Polyhedral Characterizations for Ordinal Optimization

Philipp Herrmann, Kathrin Klamroth, Stefan Ruzika, Michael Stiglmayr, Julia Sudhoff

Ordinal optimization concerns mathematical optimization problems where the objective is to find optimal solutions based on ordered categories rather than precise numerical values. We present a unified theoretical framework for ordinal optimization in mathematics, where optimization problems are formulated using categorical rather than numerical rankings. Unlike traditional optimization that relies on quantitative comparisons, ordinal optimization addresses problems where natural orderings exist but precise numerical values may be absent or inappropriate, such as comparing bicycle routes with different combinations of "safe" and "unsafe" road segments. Our main contribution is an axiomatic foundation consisting of six fundamental axioms that any suitable order must satisfy for effective ordinal optimization. We establish a correspondence between the class of orders satisfying these axioms and a specific family of convex cones, providing a complete characterization in terms of polyhedral cones. A key structural result concerns the properties of the associated tail cone. We develop a linear transformation framework based on polyhedral cones that extends the approximation results of Papadimitriou and Yannakakis to the ordinal optimization setting. However, our analysis reveals computational limitations: for polyhedral cones with high complexity, the resulting algorithms exhibit exponential runtime behavior proportional to the number of hyperplanes defining the cone. Our work provides both theoretical foundations and practical insights for researchers working with optimization problems involving categorical or ordinal data, with particular relevance to applications in operations research, decision theory, and multi-criteria optimization.

2 - Generalizing Hyperboxing Algorithms for Diverse Domination Cones

Mara Schubert

Explicitly calculating the non-dominated set of a multi-criteria optimization (MCO) problem is seldom possible. Instead, many algorithms aim to determine a set of points that effectively represent the entire non-dominated set. Among such algorithms are hyperboxing algorithms. These algorithms divide the objective space into hyperrectangles to iteratively reduce the area where additional non-dominated points may exist. A key concept is that identifying a non-dominated point allows excluding the area dominated by this point and the area where any point would dominate it. The remaining space is divided into boxes, and a solution to the MCO problem within the largest such box is sought. Most hyperboxing algorithms are designed for MCO problems with respect to the positive orthant as domination cone. This is reflected in two stages: once when solving the MCO problem and once when constructing the boxes. We present an adaptation of a hyperboxing algorithm where the construction of boxes is not necessarily based on the domination cone, provided certain conditions are met. This adaptation does not change the convergence properties of the algorithm. However, it significantly generalizes the types of domination cones that can be addressed by the hyperboxing algorithm. Notably, it is applicable even to non-polyhedral domination cones, making it more versatile than many other algorithms that systematically enhance approximation quality in the objective space.

■ TA-06

Thursday, 8:45-10:15 - Room: H9

Prescriptive Analytics: Sales, Logistics and Industrial Analytics

Stream: Analytics, Data Science, and Forecasting
Invited session
Chair: *Ralph Grothmann*
Chair: *Thomas Setzer*

1 - Machine predictive maintenance to prevent defects using Decision tree and Random forest

Pavee Siriruk

Defect reduction remains a key priority in manufacturing, with the integration of technologies such as the Internet of Things (IoT), machine learning, artificial intelligence, and big data analytics. Predictive maintenance (PdM) has become a critical strategy, using sensor data and advanced algorithms to forecast equipment failures, extend asset lifespans, and improve operational efficiency. The large-scale data collection enhances the accuracy of predictions, enabling timely interventions and reducing the risk of unexpected downtime. In this paper, the factors influencing the occurrence of defects in hard disk drive components are examined using two classification techniques: Decision tree (DT) and Random forest (RF). Three primary datasets are typically split into training and test subsets with ratios of 80:20 and 70:30 to assess model accuracy and ensure reliable predictions, as evaluated using the confusion matrix. Manual and automatic (via GridSearchCV) hyperparameters tuning are applied to optimize the model, thereby enhancing prediction accuracy. The comparison of models across datasets revealed that the random forest model, with manual hyperparameter tuning using data split ratio of 80:20 with Dataset 2, achieved the highest precision and accuracy. An analysis of feature importance was conducted, with the highest score identifying the key factors contributing to the occurrence of the defect under consideration.

2 - Discounted Sales of Expiring Groceries: The Challenge of Forecasting Demand

David Winkelmann

Approximately 11 million tons of food are discarded annually in Germany, with over 10% attributable to the retail sector. In collaboration with the German government, major retailers have committed to halving food waste by 2030. While some retailers have initiated partnerships with aid organisations, price reductions for units nearing their expiration date are another commonly employed strategy. However, the impact of such price adjustments on sales volume remains to be investigated. In particular, enhanced sales typically affect demand forecasts for subsequent periods, potentially leading to continued overestimation of actual demand and further waste. Utilising data from a leading European grocery retailer, this study addresses the incorporation of price-discounted sales into demand forecasting models. The aim is to contribute to the reduction of food waste in the retail sector by optimising pricing strategies for expiring groceries and adjusting demand forecasts accordingly.

3 - Uncovering Factors Affecting Manufacturing Quality: Causal Discovery from Embedded Features in Manufacturing Data

Won Sang Lee

Recently, there is growing interest in data-driven quality improvement and defect reduction using AI. Many recent approaches rely heavily on deep learning techniques that use large numbers of features. Unfortunately, these methods often experience limited interpretability and lack efforts to uncover the systematic relationships among features. However, in manufacturing, features are not isolated; they are generated through the interaction of facility configurations, environmental variables, and operational settings. These factors influence outcomes via intricate pathways. Thus, identifying the causal structure among features could offer more actionable and effective insights for process optimization. To address this, a novel approach is proposed to integrate embedding representation with causal discovery. First, embedding techniques allow for the transformation of fragmented feature data into compact, informative representations, since the sensor-derived features are often high-dimensional, fragmented, and difficult to interpret. Once embedded, these embeddings are analyzed using causal discovery to reveal underlying causal pathways and estimate their effect. Then, the proposed method is empirically applied to the dataset concerning failure events in rotating machinery. The sensor-based features are embedded to represent the operational state of machines, and causal inference is conducted on these embeddings. The results effectively identify important embeddings that significantly contribute to failure events and uncover the causal relationships among them. The proposed framework provides a foundation for scalable and interpretable quality improvement strategies in future manufacturing research.

■ TA-07

Thursday, 8:45-10:15 - Room: U2-205

Quantum Computing & OR

Stream: Simulation and Quantum Computing
Invited session
Chair: *Maximilian Moll*

1 - Quantum Subroutines in Branch-Price-and-Cut for Vehicle Routing

Friedrich Wagner, Frauke Liers

Motivated by recent progress in quantum hardware and algorithms researchers have developed quantum heuristics for optimization problems, aiming for advantages over classical methods. To date, quantum hardware is still error-prone and limited in size such that quantum heuristics cannot be scaled to relevant problem sizes and are often outperformed by their classical counterparts. Moreover, if provably optimal solutions are desired, one has to resort to classical exact methods. In this work, we demonstrate how quantum heuristics with limited resources can be integrated in large-scale exact optimization algorithms for NP-hard problems. To this end, we consider vehicle routing as prototypical NP-hard problem. We model the pricing and separation subproblems arising in a branch-price-and-cut algorithm as quadratic unconstrained binary optimization problems. This allows to use established quantum heuristics like quantum annealing or the quantum approximate optimization algorithm for their solution. A key feature of our algorithm is that it profits not only from the best solution returned by the quantum heuristic but from all solutions below a certain cost threshold, thereby exploiting the inherent randomness is quantum algorithms. Moreover, we reduce the requirements on quantum hardware since the subproblems, which are solved via quantum heuristics, are smaller than the original problem. We provide an experimental study comparing quantum annealing to simulated annealing and to established classical algorithms in our framework. While our hybrid quantum-classical approach is still outperformed by purely classical methods, our results reveal that both pricing and separation may be well suited for quantum heuristics if quantum hardware improves.

2 - Comparison of Quantum Approximate Optimization Algorithm across a variety of problems

Sascha-André Schuster, Rudy Milani, Maximilian Moll, Stefan Wolfgang Pickl

Quantum computing offers interesting avenues to tackle computationally intensive problems in operations research. In this work, we perform a systematic comparison of variants of the Quantum Approximate Optimization Algorithm (QAOA) applied to several combinatorial optimization problems. The QAOA variants considered vary in the design of their employed Hamiltonians and parameterization techniques. Each variant is assessed in terms of its task performance and efficiency as well as required resources (number of qubits). A secondary goal of this study is the delivery of benchmark results beyond the commonly studied Max-Cut problem which dominates the literature. The results achieved provide grounds for further evaluations including real quantum hardware.

3 - Gradient-free Optimization in Quantum Reinforcement Learning

Maximilian Moll, Stefan Klug

With quantum computing hardware improving at impressive speed, more and more ideas are being developed how NISQ machines can be used in practice. One popular idea is using quantum variational circuits in place of classical neural networks. While they are typically requiring much smaller models than their classical counterparts, their optimization can still lead to performance issues as the parameter-shift rule implies that circuit evaluations scale linearly in the number of parameters. With speed being essential problem on current machines, in particular on cloud devices, this can extend compute time significantly. Thus, recently, parameter-free approaches were explored with good results. Here, we investigate across several environments, how well these results transfer to quantum reinforcement learning. A particular focus will be on a fairly simple 1+1 evolutionary algorithm which has the added benefit of few hyper parameters. The performance across algorithms is being compared to that of traditional gradient-based training in terms of training quality as well as number of evaluations needed. Additional comparisons are being drawn between hyper parameter settings across different environments.

■ TA-08

Thursday, 8:45-10:15 - Room: H8

Technology, Trust, and Tensions: Strategic Behavior in Supply Chains

Stream: Game Theory and Behavioral Management Science
Invited session
Chair: *David Wuttke*
Chair: *Sairam Sriraman*

1 - Efficiency and Fairness in Resource Allocation: The Role of Outside Options

Andreas Gernert, Thomas Breugem

Persistent drug shortages in Europe have prompted many countries to adopt national stockpiling strategies, prioritizing autonomy over collaboration. While this ensures access for some, it risks exacerbating inequities across the region. In response, the European Commission has proposed centrally managed cross-national stockpiling to promote both efficiency and fairness. However, cooperation is viable only if countries find the joint allocation preferable to their outside options. We study this challenge through a general resource allocation model where a principal allocates resources among agents with outside options. We analyze how these constraints reshape the efficiency-fairness trade-off; specifically, the price of fairness (the efficiency loss from imposing fairness), and the loss of fairness (how outside options reduce the welfare of the least well-off). Applying the model to medicine stockpiling, we offer actionable insights for equitable and stable policy design.

2 - The effect of demand sharing behavior on the bullwhip effect in the semiconductor industry

Isabella Lippert, Hans Ehm, David Wuttke

Supply chains continue to suffer from the bullwhip effect, where demand variability is amplified as orders move upstream. Despite decades of research and operational improvements, this phenomenon remains persistent and disruptive. Its impact has been severe in the semiconductor industry, where inherent long production times magnify the consequences. Recent disruptions have revived calls for improved coordination mechanisms, including initiatives to share "true" demand across tiers of the supply chain. Demand sharing appears to be a promising solution: accurate demand forecasts from downstream firms could help upstream firms plan more effectively, reducing volatility and inefficiencies.

Does such information sharing work in practice? More critically, do downstream firms share truthfully? In industries like semiconductors, characterized by scarce capacity, long lead times, and volatile demand, OEMs may strategically inflate forecasts to secure future capacity or buffer against uncertainty. Can strategies such as introducing an additional anonymous forecast overcome these tactically induced shortfalls?

This paper examines whether demand sharing mitigates the bullwhip effect and/or it becomes a new arena for strategic behavior. We investigate this question through three hypotheses, focusing on how downstream firms report demand and how this affects upstream dynamics. To test these hypotheses, we adapt the MIT Beer Game to capture the unique structure of semiconductor supply chains, modifying the number of tiers, the lead time configuration, and the information environment. Most notably, we enable downstream firms to share demand forecasts with the rest of the supply chain, while allowing them to deviate from the truth if they believe it serves their interests.

3 - Supply Chain Finance Technology: Blockchain versus AI
Sairam Sriraman, David Wuttke

Fintechs are seeking to enhance supply-chain finance (SCF) solutions by implementing two distinct technological solutions: blockchain-enabled supply chain finance solutions (BCF) and AI-driven supply chain finance (AIF) solutions. Choosing between these two solutions is non-trivial as they differ fundamentally, and neither can be deemed superior. Additionally, there is considerable uncertainty surrounding their future development. We use two frameworks to propose the technology choice, grounded in financing frictions and innovation adoption. We identify two key frictions: opportunism and bounded rationality. Further, efficiency gains and trends are two key motives driving innovation adoption. We propose that opportunism favors BCF, whereas bounded rationality favors AIF. Further, we suggest that the presence of technological uncertainty uniformly shifts the preference towards AIF, where firms follow the current AI trend. We provide insight into our hypotheses through experiments with human subjects.

■ TA-09

Thursday, 8:45-10:15 - Room: H15

OR Software in Practice

Stream: Software for Operations Research
Invited session
Chair: *Jens Schulz*

1 - Conference Scheduling in practice with Gurobi: A multi-objective approach
Stefan Heinz

Scheduling talks for a conference is a challenging task due to the combination of general constraints and individual preferences. General restrictions include factors such as room capacities, equipment availability, and time slot limitations, while personal constraints may encompass speaker availability, travel schedules, and preferred presentation times. Furthermore, organizers often aim to balance session topics, avoid conflicts between talks of similar interest, and ensure an overall coherent schedule.

In this work, we present a multi-objective optimization approach to address the complexities of conference scheduling. Our methodology considers both hard constraints that must be strictly satisfied and soft constraints that capture speaker and organizer preferences, which are optimized as part of the objective function. By incorporating multiple conflicting goals, such as minimizing scheduling conflicts while maximizing speaker satisfaction, we demonstrate how to generate high-quality schedules that are both feasible and practically desirable.

We illustrate our approach through a real-world example that emerged in the context of organizing a mid-sized conference. This case study highlights the challenges of the scheduling process and showcases the effectiveness of our method in generating balanced and satisfactory timetables under realistic conditions

2 - Enhancing Energy Planning with Gurobi: Bridging Historical Challenges and Modern Optimization Tools
Christine Tawfik

Mathematical optimization has played a crucial role in the energy sector since its introduction in the mid-20th century. Production and plant operations have always required complex planning optimization to account for all the involved and highly intertwined decision factors. Over the past decades, energy modeling has significantly evolved, yet practitioners continue to face persistent challenges in accurately capturing system complexities and solving large-scale optimization problems. More recently, against the backdrop of energy transition and the incorporation of renewable resources, new challenges have emerged to accurately capture the fluctuating market supply and demand, as well as to evaluate decisions by weighing both economic and environmental considerations.

This talk begins with a brief historical overview of energy modeling, highlighting recurring pain points such as scenario management, model scalability, and solution interpretability. We will touch upon relevant aspects related to unit commitment problems, investment planning and integration of distributed energy resources.

We then explore how Gurobi's advanced features — such as multi-scenario modeling and multiple objectives — can directly address these issues, offering energy modelers intuitive and adaptable mechanisms to precisely represent their problems. Additionally, we dive into some of Gurobi's diagnostics tools to examine their benefit in analyzing and interpreting solutions. By aligning the sector needs with modern solver capabilities, this session aims to equip attendees with practical strategies to enhance energy modeling accuracy and performance.

3 - Generative AI in Decision Support Tools
Jens Schulz

The field of generative artificial intelligence (GenAI) has seen exponential growth over the past few years in research papers and publications. The techniques have gained traction across industries. A hype train is rolling around how to bestleverage GenAI in the fields ofOperations Research: code generation to increase productivity, chatbots for documentation, generation of mathematical optimization models - justto name a few. Large language models (LLMs) occasionally produce incorrect or misleading results, a phenomenon commonly called "hallucinations". Besides basic inaccuracies, there are also considerations around data exposure, data leakage, privacy violations, copyright violations, biased answers, dangerous or unethical usage, inappropriate language and malicious code. Best practices need to be followed to responsibly apply GenAI in decision support tools! Our examples are focused on developer and user productivity. They demonstrate how GenAI chatbots can be integrated into Decision Support Applications. It is important to balance innovation with risk mitigation when leveraging GenAI for critical decision-making tasks. We are advocating a holistic approach that combines technological advancements with ethical considerations and human oversight.

■ TA-10

Thursday, 8:45-10:15 - Room: H16

Fulfillment Operations I

Stream: Supply Chain Management and Production
Invited session
Chair: *Anton Klymenko*

1 - Depalletization planning in a wholesale warehouse with uncertain retrieval sequence
Benjamin Riedel, Simon Emde

Depalletization planning is a critical challenge in wholesale warehouses, where customer orders are fulfilled from a forward picking area and replenished from a reserve storage area. The uncertainty of retrieval sequences, limited storage capacity, and heterogene- ity of items can lead to inefficient depalletization strategies, resulting in significant costs and delays. To address this challenge, we propose a multiple-scenario approach (MSA) that generates a set of realizations of future requests and solves a deterministic problem for each scenario. We show that even solving one deterministic scenario to optimal- ity is NP-hard, and therefore introduce heuristics to solve the scenarios efficiently. Our results demonstrate that even a modified MSA approach that doesn't require solving a computationally expensive mixed-integer program (MIP) significantly outperforms the decision rules used in practice, reducing the number of depalletizations needed by 70%. Furthermore, our modified MSA approach outperforms an optimized version of the pol- icy function used in practice by 11%. Reducing the number of depalletizations leads to shorter delays in the picking area, resulting in significant cost savings, better resource utilization, and improved customer satisfaction.

2 - The Stochastic 3D Bin Selection Problem: Branch-and-Repair for Multi-stage Stochastic Programs
Pirmin Fontaine

E-commerce is continuously growing, resulting in an increasing number of parcels every year that is shipped around the globe. One major challenge is the poor utilization of resources resulting from not well-packed trucks, containers, and wrong-sized parcels. Decreasing the unused space in parcels would allow to pack goods more efficiently and reduce the number of needed vehicles. Therefore, also the portfolio of parcel types on stock is important for e-commerce retailers.

We want to address this problem in a dynamic setting with stochastic demand over longer planning horizons. The problem is formulated as a multi-stage stochastic program where the design of the portfolio has to be fixed in the beginning, but the ordering and inventory of parcels can be adjusted at each stage. Then, three-dimensional bin packing problems must be solved in each stage and scenario. We develop a branch-and-repair method to solve the problem efficiently. Specifically, we develop a fast approximated and a slow but optimal repair strategy and show how to combine both.

The numerical results based on real-world data show that branch-and-repair scales well and can solve large multi-stage stochastic programs to optimality.

3 - Decentralised lot sizing: Collaboration and smart contracting
Anton Klymenko, Margaretha Gansterer

Collaborative lot sizing usually relies on a centralised decision-maker to reap the benefits of joint operations. While this often leads to optimal results, concerns about transparency and dependency prevent agents from working together in practice. We aim to explore an alternative approach to decentralisation in lot sizing using smart contract auctions. We develop and compare two models: a centralised optimiser that achieves the best possible objective value and a decentralised mechanism where agents submit self-generated bids. An off-chain combinatorial algorithm determines the optimal allocation, and the results are published on-chain via smart contracts to ensure transparency and auditability. We also investigate the role of smart contracts in contracting for lot sizing. Preliminary results suggest that while the decentralised model worsens the objective value, increased incentives for collaboration can compensate for this trade-off. Based on a computational study, the potential of smart contracts to enable dynamic real-time pricing and enhance transparency is analysed.

4 - Towards a Machine Grouping Logic for Cell Formation aligned with Plant Layout Efficiency, Operational Costs Anticipation, and Market Customization Requirements
Soukaina Triki, Taieb Mellouli

Modern markets increasingly demand high product variety with short lead times, pushing producers to design effective manufacturing systems aligned with mass customization. This challenges classical layouts: flow shops offer high efficiency for mass production, while process layouts provide flexibility for customized jobs but at higher logistical costs. As a compromise, cellular manufacturing based on Group Technology (GT) proposes grouping machines and parts to emulate the efficiency of flow shops and the flexibility of job shops. However, our critical analysis of the classical Cell Formation (CF) Model supporting GT reveals structural limitations. By examining benchmark instances, we show that CF evaluation metrics based on Exceptional Elements (EE), voids, and grouping efficacy, though useful for assessing clustering, fail to accurately anticipate operational in-plant logistical costs directly affected by key layout factors such as cell size, spatial separation, and inter-cell movement complexity. These limitations are caused by a disconnect of grouping decisions to the requirements of an effective Inter-Cell plant layout for variant-rich production. Our argumentative and experimental analysis of CFP limitation types shows that voids fail to accurately capture intra-cell movement costs, which depend on cell size. More critically, classical CFP minimizes only the total number of EEs, without differentiating the distribution of their associated out-of-cell operations among cell-to-cell (c2c) connections. The fewer these necessary c2c connections, the closer a placement of related cells is possible in the layout. The integration of this aspect in modeling (also part-wise) is a main step towards a better anticipation of operational costs in the machine grouping phase.

■ TA-11

Thursday, 8:45-10:15 - Room: U2-200

Vehicle Routing

Stream: Heuristics, Metaheuristics and Matheuristics
Invited session
Chair: *Andreas Fink*

1 - Branch-and-Cut POPMUSIC for the Electric Vehicle Routing Problem with Time Windows
Lelisa Bijiga, John Warwicker, Steffen Rebennack

Advancements in computer hardware and commercial software have enabled the use of branch-and-cut (BC) methodologies to address medium-scale vehicle routing problems (VRPs). Despite the introduction of efficient heuristics in the literature, tailoring these approaches to suit various VRP variants, such as the Electric Vehicle Routing Problem with Time Windows (EVRPTW), remains a difficult task. EVRPTW is an extension of the classic VRP with Time Windows, in which internal combustion engine vehicles are replaced by electric vehicles. In this study, we explore the potential of combining BC techniques with decomposition strategies through constrained k-means clustering. We develop a POPMUSIC matheuristic that only relies on BC, which can be implemented using commercial optimisation software like Gurobi. Our methodology begins by decomposing the customers into geographical-based clusters, thereby imposing a manageable size for the subproblems and facilitating the efficient application of BC. These subproblems are solved iteratively to derive a comprehensive solution. We adapt new battery infeasibility inequalities and incorporate them into Gurobi, along with capacity cuts and default cuts, to tighten the linear programming relaxation of the MILP model and show that it can improve the solution quality through extensive computational experiments. We demonstrate the effectiveness of our approach on known benchmark instances of EVRPTWs and compare it with state-of-the-art exact solutions. Our result shows that the approach achieves comparable or better performance, especially on larger problems.

2 - CO2e-Specific Heterogeneous Vehicle Routing Problems with Simultaneous Pickup and Delivery
Prateek Gupta, Devanand Devanand, Jorge Augusto Meira, Antonio Ken Iannillo, Danilo D'Aversa, Daniel Pedrozo

We propose a hybrid approach for the Simultaneous Pickup and Delivery Vehicle Routing Problem (VRPSPD) with a heterogeneous fleet, which incorporates fuel-based emission parameters into the optimization objective and ultimately estimates carbon dioxide equivalent (CO2e) emissions. Our method combines a greedy insertion heuristic with swap-based local improvements that rapidly generates high-quality initial solutions by modeling fuel consumption based on vehicle load, speed, and other route-dependent factors. These solutions are refined using a mixed-integer formulation under a fixed time limit that balances both operational and environmental objectives. The resulting routes are then evaluated to provide estimates of CO2e emissions. This two-stage framework ensures feasibility, improves solution quality, and enables sustainable routing decisions. We conduct a comparative study using real-world logistics data ranging from 20 to 55 service points with diverse demand distributions, and demonstrate a 15% reduction in emissions, outperforming baseline method of Google Routing. To our knowledge, this is the first work to benchmark a CO2e-focused VRPSPD formulation against industry-standard solvers while respecting driver work-hour limits, providing a scalable and practical tool for sustainable logistics planning

■ TA-12

Thursday, 8:45-10:15 - Room: H10

AI for Optimization Modeling

Stream: Artificial Intelligence, Machine Learning and Optimization
Invited session
Chair: *Mohsen Nafar*

1 - Reinforcement Learning for Teaching LLMs to Derive Linear Programs
Florian Roland Breda, Ulf Lorenz

Large Language Models (LLMs) have the potential to assist humans in solving complex problems objectively and efficiently, even when users lack formal knowledge of mathematical optimization. However, LLMs do not yet possess an inherent understanding of linear programs (LPs). Enabling LLMs to autonomously derive LPs from textual problem descriptions requires a structured learning approach. A reinforcement learning environment provides rewards based on the quality of generated LP formulations, guiding the learning process. The quality is assessed based on factors such as solvability, solution time, and the clarity of the formulation's explanation. Small, specialized learning environments could be particularly useful for tackling specific problem domains.

2 - Interdependence-aware Modeling, Analytics and Optimization for complex Systems' Business
Taieb Mellouli

In production systems, hierarchical interdependencies of decisions, e.g. between tactical (resource-level) and operational (activity-level) decisions, arise and integrative optimization leads to considerable additional gain. However, for complex business environments, such as airlines and hospitals, planning problems and their interdependencies are intricate, since humans are integrated at customer service (demand) side - patients in hospitals - or at resource (supply) side - crew personal in airlines. The planning of their activities (medical treatments/flights) should comply with complex working rules in case of crew (duties and pairings) and with medical/clinical standards in case of patients (patient pathways). To this side of complexity related to composition of activities, one faces another complexity of multiplicity of these activity structures within (patient/crew) flow problem settings.

A new two-dimensional aggregation scheme w.r.t designed crossed dimensions for such complexities is presented which serves as modeling, analytics and optimization design tool for complex systems' businesses. Assigning appropriate aggregation/granulation levels to each complexity dimension, one can easily characterize different decision problems at strategic, tactical and operational stages - some of those may have not been apparent in advance. Types of solution methods can also be entailed in a generic way: Most problems at aggregated levels require descriptive/predictive analytics as well as AI for learning complex structures. However, planning problems at granulated levels should be tackled by prescriptive analytics and OR. Further, interdependencies between aggregated and granulated levels of decision problems give rise to AI/OR synergies of methodologies.

3 - Each Decision Matters: Creating Word Embeddings as Part of a Historical Research Workflow
Sophie Jasmin Spliethoff

This contribution aims at exploring the incorporation of word embeddings in historical research. It demonstrates how decisions made during the working process may affect resulting interpretations and emphasises the importance of designing interdisciplinary projects that combine expertise from different relevant fields throughout all research steps. With the introduction of the printing press in the late 15th century, authors were suddenly able to publish smaller books, much cheaper and quicker than ever before. The emergence of this new medium and its usage to spread invectives in the context of the Reformation were mutually dependent. From a historian's perspective, it is of great interest to find out to what extent contemporaries already linked ideas of media forms and functions during the 16th century. Rather than drawing conclusions from individual historical statements, word embeddings prove to be a suitable method in order to thoroughly explore links made between concepts. Working with historical texts poses two main challenges: The available corpora are comparably small secondly and spelling was not standardised yet. Selecting and pre-processing input data are therefore essential to yield meaningful results. However, this entails many different options, for instance lemmatising vs. stemming terms, that must be carefully considered depending on individual research interests and resources. While digital methods may create the appearance of objectivity, this contribution sheds light on the impact of individual decisions on resulting interpretations and conclusions.

4 - A Clustering-based Variable Ordering Framework for Relaxed Decision Diagrams
Mohsen Nafar, Hamed Azami Zenouzagh, Michael Römer, Lin Xie

High-quality primal and dual bounds are critical for devising efficient exact solution approaches for Discrete Optimization (DO) problems. Decision Diagrams (DDs) provide strong and generic mechanisms for providing such bounds. This paper focuses on so-called relaxed DDs which, by merging nodes, over-approximate the solution space of DO problems and provide dual bounds the quality of which hinges upon the ordering of the variables in the DD compilation and on the selection of the nodes to merge. We present a novel clustering-based variable ordering framework for relaxed decision diagrams. In a set of computational experiments on instances of the Maximum Weighted Independent Set Problem (MWISP), we show that using this framework for compiling relaxed DDs within a DD-based branch-and-bound algorithm substantially reduces its solution time.

Thursday, 10:45-11:45

■ TB-01

Thursday, 10:45-11:45 - Room: Audimax

Plenary Talk Pisinger

Stream: PC Stream
Plenary session
Chair: *Kevin Tierney*

1 - Optimization problems in offshore wind farms
David Pisinger

Wind farms provide free and sustainable electricity, hence they play a central role in the green transition. The talk will show examples of how Decision Science has contributed to significantly bring down costs of green energy. We study the five phases of the life cycle: Area Selection, Wind farm design, Installation of a wind farm, Operations and maintenance, and End of life. We focus on the most interesting optimization models and solution methods, to give the reader an introduction to this exciting and growing research area. Several examples from our collaboration with Vattenfall will be shown to illustrate the impact of Decision Science.

Thursday, 11:45-13:15

■ TC-01

Thursday, 11:45-13:15 - Room: Audimax

Aircraft refuelling and air-rail timetable synchronization

Stream: Mobility, Transportation, and Traffic
Invited session
Chair: *Bing Liu*

1 - Optimising a Hydrogen Refuelling Infrastructure on Airports: Heuristic Solutions to the Liquid Hydrogen Aircraft Refuelling Problem
Jörn Serrer

In order to achieve the European Union's goal of being climate-neutral in all sectors by 2050, the aviation sector must provide alternative fuels to fossil jet fuel. Alongside synthetic jet fuel, so-called Sustainable Aviation Fuels (SAFs) for long-haul flights, liquid hydrogen for short and medium-haul flights is a promising energy source for green aviation. While SAFs will be able continue to use the existing jet fuel infrastructure, a second new infrastructure must be built at existing airports for liquid hydrogen. Similar to current jet fuel refuelling infrastructure, a bowser based refuelling system is the more cost-effective system for small and medium-sized airports, while large airports have a cost advantage in supplying fuel with an underground pipeline and hydrant network. However, a lack of space limits the number of bowsers that can be loaded simultaneously at a central fuelling depot, while the loading of liquid hydrogen takes considerably longer than with jet fuel. The loading of bowsers could represent an operational bottle-neck for an individual airport, which could require an airport to establish an underfloor fuelling system before cost benefits are realised. An instance generator is presented, before in a discrete Liquid-Hydrogen-Aircraft-Refuelling-Problem (LH2-ARP), the dimensions of the bowser refuelling system needed to serve aircraft with the required amount of liquid hydrogen at a given time are investigated by varying key parameters and solved by using heuristics.

2 - A Branch-and-Price-Algorithm for the Liquid-Hydrogen Aircraft Refueling Problem
Timo Helfers

In order to achieve the European Union's goal of climate neutrality in all sectors by 2050, the aviation sector must provide alternative fuels to fossil jet fuel. Liquid hydrogen is a promising energy source for short- and medium-haul flights for which a new infrastructure is needed. Similar to the current jet fuel refueling infrastructure, a bowser-based refueling system is the more cost-effective system for small and medium-sized airports. A time-discrete flow model is presented to determine the cost of the bowser infrastructure. To solve larger, more realistic instances, the model is reformulated using a Dantzig-Wolfe decomposition. The resulting master problem is solved using a branch-and-price algorithm. The columns are generated using a labeling algorithm, as the resulting subproblem is an elementary shortest path problem with resource constraints without cycles. To speed up the column generation process, the use of heuristics is discussed, and other methods such as early branching are presented. Different variations of the branch-and-price algorithms are tested using instances generated from real flight data and aprons of real airports, and the results are discussed.

3 - Passenger-Centric Synchronization of Air-Rail Timetables: A Linear Approximation Approach
Bing Liu, Christopher Szymula, Nikola Bešinović

The integration of rail and air services has been attracting increasing attention with the growing emphasis on multimodal transport systems. In this paper, we propose a passenger-centric Air-Rail Timetable Synchronization (ARTS) model to improve the passenger transfer experience. The model applies a time-shift strategy to existing rail and air timetables to provide more connections and smoother transfers for multimodal travelers. It also captures passenger itinerary shifts resulting from timetable adjustments. The underlying optimization problem is inherently nonlinear, as the objective—minimizing total passenger transfer time—depends simultaneously on timetable adjustments and the resulting passenger itineraries. To address the computational complexity, a linear approximation of the ARTS problem is formulated by discretizing continuous passenger flows into distinct passenger groups. A tailored heuristic algorithm is developed to construct these groups. Initially, a relaxed approximated problem is built by grouping passengers according to their travel paths while disregarding seat capacity constraints. Subsequently, the passenger groups are iteratively subdivided, and capacity constraints are incrementally reintroduced based on a heuristic rule, until all seat capacity constraints are satisfied. The proposed methodology is validated through a real-world case study of the Spanish air-rail transport network. Computational results demonstrate that the ARTS model effectively reduces passenger transfer times and that incorporating itinerary shifts yields more realistic and efficient synchronized timetables. Moreover, the proposed linear approximation significantly enhances computational tractability while delivering solutions of acceptable quality.

■ TC-02

Thursday, 11:45-13:15 - Room: H4

Integer Programming I

Stream: Discrete and Combinatorial Optimization
Invited session
Chair: *Thorsten Koch*

1 - Computational Aspects of Lifted Cover Inequalities for Knapsacks with Few Different Weights
Cédric Roy, Christopher Hojny

Cutting planes are frequently used for solving integer programs. A common strategy is to derive cutting planes from building blocks or a substructure of the integer program. In this paper, we focus on knapsack constraints that arise from single row relaxations. Among the most popular classes derived from knapsack constraints are lifted minimal cover inequalities. The separation problem for these inequalities is NP-hard though, and one usually separates them heuristically, therefore not fully exploiting their potential. For many benchmarking instances however, it turns out that many knapsack constraints only have few different coefficients. This motivates the concept of sparse knapsacks where the number of different coefficients is a small constant, independent of the number of variables present. For such knapsacks, we observe that there are only polynomially many different classes of structurally equivalent minimal covers. This opens the door to specialized techniques for using lifted minimal cover inequalities. In this talk we will discuss two such techniques, which are based on specialized sorting methods. On the one hand, we present new separation routines that separate equivalence classes of inequalities rather than individual inequalities. On the other hand, we derive compact extended formulations that express all lifted minimal cover inequalities by means of a polynomial number of constraints. These extended formulations are based on tailored sorting networks that express our separation algorithm by linear inequalities. We conclude the talk by a numerical investigation of the different techniques for popular benchmarking instances.

2 - Column generation for a two-dimensional multi-criteria bin packing problem
Christof Groschke, Steffen Goebbels, Jochen Rethmann

At the OR 2024 conference, we presented a mixed integer linear program (MIP) for a 2D bin packing problem in printed circuit board manufacturing. In this problem, rectangular printed circuit boards have to be packed into larger rectangular boards (bins) for production in a given multiplicity without overlapping and under certain distance constraints. Among other objectives, the number of bins, but also the number of different bin layouts, is to be minimized. Since the running times of the previously presented MIP are only acceptable for small problem instances, we now discuss a branch-and-price approach. We partition the search space by using an adapted Ryan-Foster-branching. In each node of the tree, we apply column generation. The columns that are iteratively added to a relaxed master problem represent different layouts. A pricing problem computes the layouts, separating the time-consuming constraints from the master problem.

3 - An analysis of (mixed-)integer linear programming formulations for the Maximally Diverse Grouping Problem
Arne Schulz

The Maximally Diverse Grouping Problem (MDGP) is a grouping problem that aims at assigning items to groups such that the items assigned to each group are as heterogeneous as possible. Main areas of applications are the assignment of pupils or students to groups or courses. While there can be found good heuristic solution approaches in the literature, exact solution approaches are rarely investigated and typically only able to solve small problem instances. The paper at hand discusses the two well-known model formulations for the MDGP and presents new formulations especially for the case with varying group sizes based on them. All presented and discussed model formulations are evaluated in a comprehensive computational study. The results show that branching on the item-item-assignment is superior to branching on the item-group-assignment and variables for the item-item-assignment allow for additional constraints leading to a stronger LP relaxation.

4 - A GPU accelerated variant of Schroeppel-Shamir's algorithm for solving the market split problem

Thorsten Koch, Nils-Christian Kempke

The market split problem, as introduced by Cornuéjols and Dawande (1998), is a challenging binary optimization problem that performs poorly on state-of-the-art linear programming-based branch-and-cut solvers. We present a novel algorithm for solving the feasibility version of the market split problem. It is derived from the Schroeppel-Shamir algorithm for the one-dimensional subset sum problem and is based on the exhaustive enumeration of all one-dimensional solutions of the market split problem. We utilize GPUs to efficiently evaluate these one-dimensional candidate solutions across the entire problem, yielding a hybrid CPU-GPU implementation capable of efficiently solving instances of the market split problem with up to 10 constraints and 90 variables. We demonstrate our algorithm's performance on a set of benchmark problems, solving instances of size (9, 80) in less than fifteen minutes and (10, 90) in under one day.

■ TC-03

Thursday, 11:45-13:15 - Room: H5

Maintenance Scheduling

Stream: Project Management and Scheduling
Invited session
Chair: *Jasmin Montalbano*

1 - Scheduling on uniform processors with fixed jobs

Liliana Grigoriu

We consider the problem of nonpreemptive scheduling on uniformly related machines with fixed jobs, that is, jobs that need to perform on certain machines at given times, with the aim of minimizing the maximum completion time. Fixed jobs may also represent periods where the machines become unavailable due to scheduled maintenance, or even personnel breaks. In the context of scheduling with fixed jobs, the maximum completion time of a schedule can not occur before the latest end of a fixed job. We present a polynomial algorithm, the schedules of which end within 1.5 times the maximum completion time when there is at most one fixed job on each machine. Even for same-speed processors, it is NP-hard obtain schedules that obey better bounds for this problem. Like MULTIFIT, our algorithm uses binary search to find a deadline for which a feasible schedule can be generated by using the First Fit Decreasing(FFD) algorithm to schedule the jobs in the available time intervals on machines, which are delimited by the fixed jobs, the start of the schedule, and the chosen deadline. Before attempting to schedule the jobs by using FFD, our algorithm orders these time intervals in nondecreasing order of their length, which we define to be the duration of the time interval times the speed factor of the machine on which it occurs. We present experimental results with regard to the performance of this algorithm. For example, for the special case when there is one fixed job on each machine, with machine speeds between 1 and 10, 100 randomly generated instances with 10 machines and an average of 30 jobs per machine have an average error below 0.1%, whereas 100 randomly generated instances with 5 processors and an average of 10 jobs per machine have a worst observed error below 0.9%.

2 - Improvements to Machine Scheduling with Position-Dependent Maintenance Operations

Julius Hardt, Florian Jaehn

We consider machine scheduling problems involving position-dependent maintenance. In these problems, a maintenance operation must be performed after at most a given number of jobs have been scheduled on the machine. Following the problem definition, we present some new theoretical insights and some improvements to existing results. The focus is on minimizing the maximum lateness in the one-machine scheduling problem, taking release dates and preemption into consideration. A new bound for the maximum number of maintenance operations required in an optimal solution is given. We obtain a deeper understanding of the need for fractional processing times in certain instances. Additionally, we propose a new MILP model incorporating new and already existing theoretical results and report on the computational study.

3 - Maintenance Scheduling with Conditional Generalized Temporal Constraints and Disjunctive No-Wait Constraints

Jasmin Montalbano, Jonas Saupe, Stefan Nickel

We consider a planning problem arising in the context of waterway infrastructure maintenance. Such maintenance tasks require the temporary drainage of locks and weirs, necessitating the deployment of various resources such as closure gates, watercraft and personnel. The planning objective is to find a maintenance schedule that minimizes the maximum resource capacity required at any time. This problem is known as the resource investment problem (RIP). In practice, additional constraints must be observed. First, tasks correspond to a type of maintenance work that must be carried out at a specific frequency at each building. These requirements are modeled using generalized temporal constraints where time lags vary depending on the start periods. Second, due to operational reasons, predefined groups of tasks must be executed without interruption. We refer to this problem as RIP with conditional generalized temporal constraints and disjunctive no-wait constraints (RIP-cmax-dnw). To the best of our knowledge, RIP-cmax-dnw has not been studied previously. We formulate RIP-cmax-dnw as a mixed-integer programming (MIP) model. However, obtaining an exact solution takes prohibitively long, rendering it impractical for applications, such as scenario analyses involving changes in maintenance frequencies. Complicating factors are the large number of resources and the presence of disjunctive no-wait constraints. To address this, we propose a problem relaxation by aggregating resources based on similar capacity requirements. Furthermore, we eliminate disjunctive no-wait constraints by heuristically fixing task sequences. Experimental results show a significant improvement in solving performance, making our approach suitable for scenario analyses in real-world applications.

■ TC-04

Thursday, 11:45-13:15 - Room: H6

GOR PhD Awards

Stream: PC Stream
Award Competition session
Chair: *Dominik Möst*

1 - Unrelated Machine Scheduling in Different Information Models

Alexander Lindermayr

Unrelated machines are an abstraction of many scheduling environments appearing in practical applications, where every job may be processed at a different speed on every machine. We study different optimization problems for scheduling unrelated machines in three categories of information models, which determine the amount of information of an instance an algorithm has access to. First, we consider the offline model, where all information about the instance are known to an algorithm. We show a new connection between minimizing the makespan on unrelated machines and the closely related Santa Claus problem regarding their polynomial-time approximability. Second, we consider the online model, where an algorithm has to schedule jobs over time while coping with uncertainty about the instance. In particular, we consider non-clairvoyant scheduling, where an algorithm has no knowledge about a job's processing requirements until it completes. We present algorithms with close-to-optimal competitive ratios for this problem on unrelated machines and for even more general scheduling environments using an elegant and natural allocation rule from economics. Finally, in the third part, we study the learning-augmented information model. In this recently emerging framework, an algorithm is given access to a potentially erroneous prediction, which potentially give an algorithm additional information to output a better solution. We present new prediction models for various scheduling problems, and design and analyze learning-augmented algorithms.

2 - Mixed-Integer Optimization Techniques for Robust Bilevel Problems with Here-and-Now Followers

Yasmine Beck

In bilevel optimization, some variables of an optimization problem have to be an optimal solution to another nested optimization problem. This structure makes bilevel problems a powerful tool for modeling hierarchical decision-making processes, which arise in various real-world applications such as in critical infrastructure defense, transportation, or energy. However, as they combine two different decision-makers in a single model, bilevel problems are inherently hard to solve. Further challenges arise if problems under uncertainty are considered.

In this work we highlight that the sources of uncertainty in bilevel optimization are much richer compared to single-level optimization because not only the problem data but also the (observation of the) decisions of the two players can be uncertain. The main goal of this work is the development of algorithmic approaches to solve bilevel problems in which techniques from robust optimization are used to address uncertainties. First, we present exact branch-and-cut and heuristic methods for mixed-integer linear bilevel problems with a Gamma-robust treatment of objective uncertainty. The efficiency of our methods is assessed through extensive computational studies. Second, we study the problem of determining optimal tolls in a traffic network in which travelers hedge against uncertain travel costs in a robust way. We formulate this problem as a mathematical program with equilibrium constraints, for which we present a reformulation that can be tackled using state-of-the-art general-purpose solvers. We further illustrate the impact of accounting for uncertainties on toll policies and travelers' behavior through a case study. Third and finally, we discuss two aspects related to decision uncertainty in bilevel optimization.

3 - Advancing multi-criteria energy systems analysis - new links of multi-objective optimisation, modelling to generate alternatives and energy systems modelling

Jonas Finke

The energy sector is a main source of anthropogenic carbon emissions and must therefore be transformed to limit global warming. The energy transition poses major challenges for decision-makers. Energy systems optimisation models (ESOMs) support energy planning and decision-making by generating insights into energy systems, focussing mostly on the techno-economic sphere. At the same time, many decision-makers and stakeholders are involved in the energy transition, all of whom have different and potentially conflicting interests. This results in further complexities for decision-making, which can be addressed by considering multiple decision criteria in ESOMs. Therefore, this work aims at advancing multi-criteria ESOMs, focusing on modelling to generate alternatives (MGA) and multi-objective optimisation (MOO). The following research targets are achieved. First, paradigms, strengths and limits of existing multi-criteria approaches are synthesised. Second, a new approach, modelling to generate near-Pareto-optimal alternatives (MGPA), is developed. It combines the strengths of MGA and MOO. Third, a new link between ESOMs with MGA and market equilibria is established to facilitate the economic interpretation of these models. Fourth, the flexibility, applicability and usefulness of multi-criteria ESOMs across various contexts, energy systems and criteria are demonstrated. Fifth, particularly innovative applications of MGA and MOO to energy system models are developed. Finally, the open and highly flexible ESOM framework Backbone is extended by new implementations of MGA and MOO. Overall, this work advances the field of multi-criteria energy systems analysis both theoretically and practically. Thereby it contributes to improved decision support for the energy transition.

4 - New Heuristics for Routing Problems in the E-Commerce Era

Maximilian Löffler

In the e-commerce era, efficient order fulfillment processes in distribution centers have become a key success factor. One novel technology investigated in this thesis to streamline these processes is robot-assisted order picking. In these systems, human order pickers are supported by autonomous mobile robots (AMRs), which carry bins for collecting picking orders, autonomously move through the warehouse, and wait in front of a shelf containing a requested stock keeping unit (SKU). Once a picker has approached a waiting AMR and placed the requested SKU into the respective bin, AMR and picker may separate and move toward other picking positions. In this way, pickers continuously move between different waiting AMRs without having to return to the depot. This work treats the coordination of multiple AMRs and multiple pickers to minimize the makespan. It proposes a heuristic method for the deterministic case that can handle the requirements of large e-commerce fulfillment centers and successfully solves instances with more than one thousand picking positions. Based on the obtained solutions, the performance of our picking system is compared with the traditional warehouse setup without AMR support. We find that largely improved makespans can be expected. In addition, we analyze the effects of stochastic picking times. The ripple effect caused by stochastic picking times, in which a single delay may cascade through a tightly synchronized schedule and deteriorate picking performance, can be effectively mitigated by separating the workforce into smaller subgroups.

■ TC-05

Thursday, 11:45-13:15 - Room: H7

Multiobjective Optimization 2: Continuous Problems

Stream: Decision Theory and Multi-criteria Decision Making

Invited session

Chair: *Lara Löhken*

1 - Using relative errors for solving convex vector optimization problems

Daniel Dörfler, Andreas Löhne, Rebecca Köhler

Approximately solving a convex vector optimization problem is done by approximating its upper image by finitely many points or polyhedra using any error measure to quantify the approximation quality. Only measures that depend on absolute error values are used in the literature, e.g. the Hausdorff distance for bounded problems, which don't take the scale of the upper image or the fact, that objective function values may be of different scales, into account. In this talk we propose a solution concept that depends on relative errors to approximate the upper image. We show, that within a region depending on the approximation quality and a chosen reference point the distance between points of the approximation and weakly minimal points of the vector optimization problem can be bounded. This bound increases with the distance of the points to the reference point. Points outside of the region also carry information as they are close to weakly minimal points or recession directions of the upper image. The method is applicable to arbitrary convex vector optimization problems. In particular, boundedness or polyhedrality of the ordering cone are not required. We also compare the approach with solution concepts from the literature.

2 - Low-Rank Multi-Objective Linear Programming

Pascal Zillmann, Andreas Löhne

When solving multi-objective programs, the number of objectives essentially determines the computing time. This can even lead to practically unsolvable problems. Consequently, it is worthwhile to reduce the number of objectives without losing information. In this article, we introduce a method to transform a multi-objective linear program (MOLP) into an equivalent vector linear program (VLP) with merely as many objectives as the rank of the original objective matrix. To this end, only an LU decomposition of this matrix is needed to be calculated. One of the factors then forms a new ordering cone, while the other factor remains as the objective matrix. Through several series of numerical experiments, we will show that this approach indeed leads to a significant speedup of computing time, and therefore provides a powerful technique for MOLP solving in practical concerns. As there are fewer objectives to consider, the approach additionally helps decision makers to get a better visualization as well as understanding of the actual problem. Moreover, we will point out that the equivalence of the MOLP and the corresponding VLP can be used to derive statements about the concept of nonessential objectives. Finally, we will present an idea for reducing the rank of a high-rank objective matrix by deleting the smallest singular values.

3 - An unconstrained method for nonconvex Pareto front approximation
Ina Lammel, Karl-Heinz Küfer

In multi-objective optimization, approximating a Pareto front is a common task to help a decision-maker understand his or her options. Most scalarization-based approximation schemes for nonconvex Pareto fronts use constraints on the feasible set to guide the next solution to be computed to a particular region of the Pareto front. However, many powerful specialized solvers cannot handle constraints. We propose a new algorithm for the approximation of nonconvex Pareto fronts that only solves unconstrained optimization problems if the underlying multi-objective optimization problem is unconstrained. The algorithm uses a utility function-based scalarization method that incorporates penalty functions to approximate constraints. We show the completeness of the approach, i.e. every Pareto point can be the solution of a scalarization problem. The approximation algorithm is based on approximated boxes. We provide conditions under which a solution computed with approximated constraints actually fulfills the constraints and discuss the implications for the approximation algorithm and the use of domination cones to bound trade-offs. We illustrate the performance of the algorithm with numerical and practical examples and compare it to a box-based algorithm that uses a Pascoletti-Serafini scalarization approach.

4 - Decision and Objective Space Representations (DO-REP) in Continuous Multi-objective Optimization
Lara Löhken, Kathrin Klamroth, Serpil Sayin

Representation algorithms aim to provide a discrete subset of solutions of a multi-objective optimization problem (MOP). The solution set, referred to as a representation, must ensure a particular quality with respect to a chosen measure/indicator. While recent research on representations and representation measures focuses mainly on the objective space of MOP, we aim at finding a representation of high quality both in the decision and objective space for continuous MOP.

By stating optimality conditions for weighted sum scalarizations, the Pareto front is described as a surface parameterized by the weight vector. Investigating its sensitivity wrt. variations of the weights yields a system of differential equations. Its solution is a function (depending on the weight vector) that satisfies first-order optimality conditions. Under appropriate assumptions, it yields the set of Pareto optimal solutions. Numerical solvers for differential equations are applied to approximate this function and hence the Pareto set.

The determination of solutions at specific grid points can be interpreted as a representation of the Pareto front. The resulting approximation method contrasts with other common representation approaches as it operates in the decision rather than the objective space. By using different discretization strategies (grid points, search directions, and step-lengths) in the decision space, we derive different representations that are evaluated wrt. their approximation and representation quality. Suitable quality indicators are incorporated in the approximation scheme. We analyze the effect (wrt. representation quality indicators) in the objective space when applying different discretization strategies in the decision space and thus interrelations between the two.

■ TC-07

Thursday, 11:45-13:15 - Room: U2-205

Simulation & Analysis

Stream: Simulation and Quantum Computing
Invited session
Chair: *Christian Stummer*

1 - The value of consumer heterogeneity in simulating innovation diffusion: A computational experiment based on the Bass model
Theresa Elbracht, Christian Stummer

Modeling the diffusion of innovations constitutes an established field of research. Its most prominent cornerstone, the Bass model, is based on strong assumptions, namely that (i) consumers are identical regarding their innovativeness and their propensity to conform with others and that (ii) they are embedded in a fully connected social network. Still, the model offers a reasonable estimation for the diffusion curve of many consumer products measured in terms of the R2 value. Our research addresses these two limitations and investigates the effect of allowing for individual consumer traits or embedding consumers in a more realistic social network in which some are more strongly connected with their peers than others. To this end, we ran simulation experiments for four variants of an agent-based model. In the first, we use the same parameters as Bass and replicate the diffusion curves from his analytic model. In the second model, we stick with the fully connected network but assign individual consumer traits by drawing individual parameters for each consumer agent from a normal distribution with the original parameter as the mean. In the third model, in contrast, we stick with homogeneous consumer traits but employ a scale-free social network following the Barabasi-Albert approach. In the fourth model, we combine heterogeneity regarding consumer traits and heterogeneity resulting from the scale-free social network. The best results from the four models are then compared with respect to their fitting with sales data from the real-world application cases that Bass used. We find that heterogeneity makes a significant difference in most cases, which especially holds true for the network effect but also, although to a smaller extent, for heterogeneity in consumer traits.

2 - Competitor Interference in Innovation Diffusion: An Agent-Based Simulation of Disinformation Campaigns
Frederik Tolkmitt, Christian Stummer

When an innovation enters the market, diverse communications influence consumers' adoption decisions. We distinguish three types of communication—the good, the bad, and the ugly—based on their sources, content, and intended effects. Good and bad communications are usually based on the actual performance of the product experienced by consumers and arise from consumers who want to communicate their satisfaction or dissatisfaction with the product to their peers. In contrast, ugly communication is initiated by competitors through disinformation campaigns, which aim to lower the perceived performance of the product and increase consumer uncertainty. These campaigns can take various forms: they can target different numbers and groups of consumers (e.g., highly connected opinion leaders), they can occur for varying durations and at different times during the diffusion process, and they can impart different information with different levels of credibility. In our research, we are interested in the effect of such campaigns on consumers' ambiguity regarding a new product's performance (or value proposition), which can increase uncertainty and prompt consumers to postpone product adoption. To more closely analyze the impact of disinformation campaigns and possible countermeasures, we set up an agent-based simulation in which heterogeneous consumer agents are connected within a social network, receive information, update their perceptions of the product's performance, and respond to the uncertainty created by ambiguous information.

3 - Analyzing Passenger Flows in Dwell and Waiting Areas at Querétaro Airport
Fernando Castro, Catya Zuniga, Axel Escamilla, Ayesha Lorena Macías Pérez, Jorge Enrique Leonardo Gutiérrez de Velasco Rodríguez

The Queretaro international airport (QIA) developed an analysis about the pasagger flow in the last waiting area. The observed data and the quantitative analysis, was used a data base form by passenger's age, the time inside the activities and flights. This data was important to identify the queues and to evaluate how the layout design affects the efficiency of the passagger flow.The results of this model show that the signage and the long queues affects the time of the boarding process.

The purpose of the simulation model is to predict the last waiting area capacity and determine strategies to get a better distribution and make the operational process more efficient for the QIA.

■ TC-08

Thursday, 11:45-13:15 - Room: H8

Strategic Behavior in Modern Markets

Stream: Game Theory and Behavioral Management Science
Invited session
Chair: *Philippe Gillen*

1 - Mandating Privacy Spillovers: Interoperability in Data Markets
Alexander Rasch

We study the effects of mandating interoperability in a network market. We model competition between an incumbent service that employs a data-driven business model in exchange for 'free' access to the service and a privacy-preserving entrant. On the user side, there are direct network effects and users are privacy conscious. We characterize market outcomes with and without interoperability and find that interoperability may induce data or privacy spillovers as user data are transferred across different services. Because mandating interoperability results in higher data collection levels, it can hurt user welfare if these privacy spillovers are sufficiently large. Moreover, the entrant's market share also decreases when privacy spillovers are large, that is, contestability is limited. Furthermore, we study the business model choice of the entrant.

2 - No commitment, no problem?
Philippe Gillen

Consider a first-price procurement auction in which the buyer lacks the commitment not to renegotiate with the winning seller upon con clusion of the auction. The theoretical prediction for such a setting is stark: only pooling equilibria exist in which bids are both high and uninformative to the buyer. The buyer responds by selecting a win ning seller, and making them a take-it-or-leave-it offer. This leads to higher buyer expenses than in a setting with commitment. Of course, this equilibrium requires a high degree of sophistication on the part of the sellers. We therefore take this setting to the laboratory. While we find that sellers bid significantly higher in the no-commitment set ting vis-'a-vis the setting with commitment, buyer expenses are actu ally significantly lower in the no-commitment setting. This finding holds even when providing buyer and sellers with decision support. It also holds when letting artificial intelligence partake in these auctions. These findings moderate the theoretical prediction, suggesting that, at least at this moment in time, a lack of commitment may actually be beneficial to the buyer.

■ TC-09

Thursday, 11:45-13:15 - Room: H15

Operational planning in energy systems

Stream: Energy and Sustainability
Invited session
Chair: *Lars-Peter Lauven*

1 - An approximate dynamic programming approach to the control of regenerative power systems
Florian Scholz, Christoph Schwindt

In this talk we consider a power supplier operating regenerative power plants and electricity storages. To meet the customer demands, the supplier can feed electricity generated by the power plants, released from the storages, or procured on a continuous intraday market. The supplier can also use the storages to achieve trading profits. The respective decisions must be taken immediately before the load, the utilization level of the power plants, and the market price are known. For each of these three uncertain parameters, the supplier has forecasts with known accuracies available. If the load is not entirely satisfied, the supplier bears the cost for the balancing services. The resulting control problem is modeled as a discrete-time Markov Decision Problem (MDP) on a time horizon comprising the 96 quarter hours of one day, where the states coincide with the storage levels and the actions represent procurement and sales volumes. We propose a heuristic solution method starting from an LP formulation of the average-value certainty equivalent. The LP solution is interpreted as a state-independent policy, which serves as an initial solution to the MDP. This solution is then improved using a restricted version of the MDP where only actions within a given range around the initial policy are considered. A discretized version of this problem is efficiently solved by recursively evaluating the standard Bellman equations. We present the results of a computational experiment where based on past prices and forecasts for loads and wind speeds we generate price forecasts using a neural network trained on historical data. By varying technical, environmental, and cost parameters of the problem instances, we analyze their impacts on different performance indicators of the energy system.

2 - Prototypical warm-starts for demand-robust LP-based energy system optimization
Niels Lindner, Lukas Mehl, Karolina Bartoszuk, Janina Zittel

The expressiveness of energy system optimization models (ESOMs) depends on a multitude of exogenous parameters. For example, sound estimates of the future energy demand are essential to enable qualified decisions on long-term investments. As these are inherently uncertain, ESOMs are formulated in a robust or stochastic setting. The drawback is however that the resulting large-scale problems are computationally challenging, even if they are merely based on linear programming (LP). A thorough analysis of demand sensitivity and the resulting consequences on technology investments is therefore hardly accessible.

One way to cope with demand uncertainties is to solve a number of independent demand scenarios. For LP models, this offers the potential for warm-starting the dual simplex method, as demand variations translate into changes of right-hand sides of linear constraints. However, depending on time horizon and resolution, these modifications might be too numerous, so that solving from scratch is more effective.

We therefore propose a decomposition approach to facilitate and accelerate warm-starting procedures for LP-based ESOMs with uncertain demand. The key idea is to single out prototypical and easily solvable demand slices, limited to very few time steps. We then combine the resulting optimal simplex bases to a larger one, matching energy demands with prototypes, and thereby producing more meaningful warm-starts. This principle naturally extends to ESOMs that integrate multiple scenarios into a single one, as in stochastic programming.

We evaluate the feasibility of our approach on a real-world case study, using a sector-coupled ESOM with hourly resolution for the Berlin-Brandenburg area in Germany, based on the oemof framework.

■ TC-10

Thursday, 11:45-13:15 - Room: H16

Fulfillment Operations II

Stream: Supply Chain Management and Production
Invited session
Chair: *Maximilian Schön*

1 - LOGMASTER: Design and Implementation of Immersive Real-Life Case Studies in Virtual Reality for Higher Education in Logistics and Supply Chain Management
David Flaig, Max Henning, Calvin Hofmann, Alisa Munz, Carola Schulz, Gerrit Meixner

This paper presents a virtual reality (VR)-based platform designed to enhance logistics education by providing an immersive and interactive learning environment. Targeted at master's degree programs in Supply Chain Management and Logistics, the platform aligns with the competency framework established by the European Logistics Association (ELA), specifically addressing competencies 7.4.06.03 (Implements lean warehouse policies) and 7.4.06.04 (Implements collaborative agreements with service providers) within the Warehousing domain of the Logistics Execution Level 7. Developed in Unity, the VR platform features two interconnected scenarios. The first is a warehouse simulation in which students critically assess operational inefficiencies, safety risks, and organizational shortcomings. This scenario trains learners to apply lean principles by identifying and analyzing non-value-adding activities in the logistics environment (competency 7.4.06.03). The second scenario is a VR-based office environment with networked multiplayer functionality, enabling role-play interactions between two real users: one assuming the role of a customer or principal, and the other acting as a logistics service provider (LSP). Within this scenario, participants collaboratively reflect on and discuss findings from the warehouse simulation, negotiating perspectives and potential improvements (competency 7.4.06.04). This paper presents the application design, technical implementation, and educational relevance of the platform. This work is part and funded by the European LOGMASTER project.

2 - Optimizing online order fulfillment under capacity constraints: A comparative study of allocation strategies
Lais Wehbi, Yasmin Roshandel

In e-commerce, the task of fulfilling orders under capacity constraints across multiple distribution centers is both operationally critical and computationally challenging. This study presents a comparative analysis of real time order allocation strategies, examining trade-offs between computational efficiency and fulfillment performance. We evaluate five approaches: a baseline greedy algorithm, an estimated shadow price method, a repeated ILP with predictions and a capacity aware heuristic. We also assess the impact of allowing orders to be split among multiple centers.

Our empirical analysis, conducted using operational data from a large-scale retailer, shows that the capacity-aware heuristic reduces total costs by 15% and unfulfilled orders by 28% compared to the greedy baseline, while maintaining comparable computational speed. The ILP with predictions achieves near optimal performance with a 21% optimality gap, albeit with longer computational runtime. Additionally, we find that allowing order splitting further reduces total cost by 19% compared to the non-split greedy baseline, though is not always applicable in live environments. A novel contribution to our work is a dynamic capacity penalty factor incorporated to the heuristic, which works to prevent premature depletion of centrally located warehouses within reasonable computational speed, a common limitation that is typically observed in myopic strategies.

Our findings offer practical insights for retailers seeking to optimize fulfillment networks, particularly during peak demand periods, demonstrating that substantial efficiency improvements are achievable without complex computational infrastructure.

3 - Industrial-scale load carrier to truck assignment with implicit truck loading constraints
Daniel Wetzel, Jakob Schulte, Mohamed Amine Khatouf, Michael Römer, Kevin Tierney

In modern supply chains, the efficient transportation of goods is crucial for ensuring timely and effective deliveries. This work introduces a novel approach to optimize load carrier to truck assignments within supply chains. By integrating implicit truck loading constraints into an assignment formulation, we determine the number of trucks needed each day to meet resource demands and ensure on-time delivery. We develop a mixed-integer linear programming formulation that reliably provides lower and upper bounds, along with a heuristic, to minimize total supply chain costs, including item costs incurred from late shipments and truck costs. Through computational experiments in a detailed case study provided by Renault, a major car manufacturer, we demonstrate the effectiveness of our approach in improving decision-making and optimizing truck usage, considering up to 15,000 trucks and 210,000 items. The proposed approach not only reduces costs and supports more sustainable supply chain practices, but also provides decision-makers with reliable minimum and maximum cost estimates for the considered supply chains within minutes. We benchmark our results against a state-of-the-art algorithm from the literature, underscoring the value of integrating truck loading anticipation in assignment models to minimize supply chain costs and accurately determine the number of trucks required for efficient operations.

4 - Multi-Stage Aggregate Production Planning from a Lean Resilience Perspective
Maximilian Schön, Chenghao Dai, Frank Herrmann, Thorsten Claus

In today's increasingly uncertain and dynamic environment, supply chain resilience has become a critical capability for companies to prepare for, respond to, and recover from disruptions. Classically, resilience is known as a driver of costs. Therefore, recent research has established the concept of lean resilience, balancing resilience and efficiency in the sense of a cost-benefit analysis. Traditional ways of dealing with operational fluctuations, like safety stock and capacity, are insufficient to compensate for large-scale disruptions or would, if nonetheless utilized for this purpose, lead to unnecessarily high costs. Therefore, capabilities that are specifically designed to deal with large-scale disruptions need to be incorporated.

In this contribution, a multi-stage aggregate production planning problem is addressed to facilitate resilient planning from a practical perspective in a disruptive context. A multi-objective, stochastic model for aggregate production planning is proposed, integrating both the economical objective and resilience metrics, along with capabilities to compensate for large-scale fluctuations along several dimensions. The probability distribution of the disruption scenarios is derived from an analysis of relevant news collected from the internet. The model is then applied to a realistic case study of a consumer electronics supply chain facing the risk of disruptive events. Lastly, these numerical experiments are utilized to evaluate the results of this application.

■ TC-11

Thursday, 11:45-13:15 - Room: U2-200

Theory & Methods

Stream: Pricing and Revenue Management
Invited session
Chair: *Rouven Schur*

1 - Fairness and Efficiency for Scarce Resource Allocation
Alejandro Lamas, Hamed Jalali, Mosayeb Jalilian

We consider a decision-maker that aims to balance revenues and fairness when allocating a scarce resource among two customer classes. Customers' requests arrive stochastically. This problem fits to the allocation of public goods, like medical supplies, ticket to massive events and transportation, etc. Different to our work, current literature focuses on either fairness or revenues. We propose several fairness measures based on both demand fill rate and Rawls' notion of fairness, i.e., we maximize the minimum expected fill rate and the expected minimum fill rate. For scenarios where requests of classes realize sequentially, we characterize both revenue optimal and fair allocations; we develop a dynamic programming approach for more complex environments in which arrivals pattern is uncertain. In addition, we study how to relax fairness considerations so managers can control the trade-off between revenues and allocation equity.

2 - Dynamic nonlinear pricing in the presence of multiunit demand and two-dimensional customer heterogeneity
Rouven Schur

In many industries, such as retail, firms often face customers who buy multiple units at once and have traditionally relied on nonlinear pricing to influence purchase quantities. While this approach can be effective, it does not offer the flexibility of dynamic pricing - an increasingly important strategy due to advances in technology. Conversely, ignoring multiunit demand in a dynamic pricing context can lead to suboptimal prices and missed revenue opportunities. To address this, we present a multiunit dynamic pricing framework that integrates the strengths of nonlinear and dynamic pricing, allowing firms to quote distinct prices for different batch sizes over time. Our approach to customer choice diverges from traditional models by accounting for two-dimensional customer heterogeneity - product attraction and consumption - both private information. These characteristics are modeled via separate random variables in the willingness-to-pay formulation, resulting in more complex purchase probability expressions than in conventional one-dimensional settings. We formulate a state-wise optimization problem from a monopolistic firm's perspective, exploring scenarios in which the firm observes neither, one, or both characteristics at customer arrival. For each, we derive optimality conditions and, in certain cases, present closed-form solutions. When no customer-specific information is observable, the model's complexity can be mitigated by a refined formulation that serves as an upper bound and, under specific conditions, is optimal for the original problem. We also develop a heuristic that yields near-optimal solutions while substantially reducing computational requirements.

■ TC-12

Thursday, 11:45-13:15 - Room: H10

Insights through Unsupervised Learning

Stream: Artificial Intelligence, Machine Learning and Optimization
Invited session
Chair: *Thi Huong Vu*

1 - Optimizing Medical Drone Dispatch and Charging Operations Using Deep Reinforcement Learning
Abolfazl Maleki, Amin Asadi, Breno Alves Beirigo, Derya Demirtas, Erwin W. Hans

Drones have become a vital solution for healthcare logistics, enabling the delivery of medical supplies to remote or disaster-affected areas where traditional transportation methods (e.g., trucks) face significant challenges. It is crucial to manage limited resources and minimize operational costs to ensure an efficient drone delivery, usually facing demand uncertainty. Delivery drones, characterized by their limited flight range, require slow/fast recharging to maintain continuous delivery operations. Nonetheless, the trade-offs in charging strategies introduce conflicting objectives: excessive use of fast charging can ensure high drone availability but accelerates battery degradation, while reliance on slow charging preserves battery life but may reduce the number of drones ready for deployment. To address this issue, we propose charging/dispatching policies that balance drone availability to satisfy medical demands with operational charging costs. Specifically, we introduce a Stochastic Multi-class Allocation and Recharging model for Transportation (SMART), which optimizes medical item deliveries by considering both fast- and slow-charging strategies. We formulate this problem using a novel Markov Decision Process (MDP) framework. To efficiently optimize dispatching (i.e., selecting which drones to send on missions) and recharging decisions (i.e., determining when and how many batteries to charge via either slow or fast chargers), we then develop a deep reinforcement learning approach. Computational experiments demonstrate the effectiveness of our model, providing valuable insights into improving the sustainability and cost-efficiency of drone-based healthcare logistics.

2 - Unsupervised classification of large-scale text-based datasets with Large Language Model Embeddings
Tim Kunt, Ida Litzel, Thi Huong Vu

We propose an unsupervised classification approach to large-scale text-based datasets using Large Language Models. Large text data sets, such as publications, websites, and other text-based media, inherit two distinct types of features: (1) the text itself, its information conveyed through semantics, and (2) its relationship to other texts through links, references, or shared attributes. While the latter can be described as a graph structure, enabling us to use tools and methods from graph theory as well as conventional classification methods, the former has newly found potential through the usage of LLM embedding models. Demonstrating these possibilities and their practicability, we investigate the Web of Science dataset, containing 70 million scientific publications through the lens of our proposed embedding method, revealing a self-structured landscape of texts. Further, we discuss strategies to combine these emerging methods with traditional graph-based approaches, potentially compensating each other's shortcomings.

3 - Clustering scientific publications: lessons learned through experiments with a real citation network
Thi Huong Vu, Thorsten Koch

Clustering scientific publications helps uncover research structures within bibliographic databases. Graph-based methods such as spectral, Louvain, and Leiden clustering are commonly used due to their ability to model citation networks. However, their effectiveness can diminish when applied to real-world data. This study evaluates these clustering algorithms on a citation graph of about 700,000 articles and 4.6 million citations from the Web of Science. The results show that while scalable methods like Louvain and Leiden perform efficiently, their default settings often yield poor partitioning. Meaningful outcomes require careful parameter tuning, especially for large networks with uneven structures, including a dense core and loosely connected papers. These findings highlight practical lessons about the challenges of large-scale data, method selection and tuning based on specific structures of bibliometric clustering tasks

Thursday, 14:30-16:00

■ TD-01

Thursday, 14:30-16:00 - Room: Audimax

Hub location and service network design

Stream: Mobility, Transportation, and Traffic
Invited session
Chair: *Alexander Helber*
Chair: *Okan Dukkanci*

1 - A Pricing Bilevel Hub Location Problem with Vehicle Based Costs
Nele Pommerening, Maja Hügging, Christoph Buchheim, Uwe Clausen

In this contribution we consider a bilevel variant of the well-known single allocation hub location problem involving vehicle capacities in the cost function. It is not surprising that this problem inherits its NP-hardness from the classical hub location problem.

Here, the bilevel structure is set up as follows: The leader is a logistic service provider who aims to maximize her profit, while the customers (the follower) want to ship their transport goods. First, the leader decides where to build the hubs and sets a price per unit of transport good for every transportation route. After this, every customer decides based on his budget whether to book the shipment or not. Every customer has an individual budget and always books the transport, if he can afford it. The leader knows the budget of all customers and has to maximize her profit, which is the price the customers have to pay minus the costs caused by the required transport vehicles. As usual, the transportation costs between the hubs are discounted.

The advantage of considering vehicle costs is that they commonly arise in practical applications. However, they do not rise linearly in the transport volume. In a recent publication we dealt with the latter bilevel problem with linear costs, deriving a Lagrangian Decomposition into two smaller problems (one is in P) leaving no duality gap. Now, the same approach results in a duality gap for vehicle-based costs, even if all customers have uniform transport volume. However, this can be repaired by including particular redundant constraints into the respective bilevel problem.

2 - Optimal Locations for Switching Between Conventional and Automated Tractors: Placing Transfer Hubs for Electrified Road Freight Logistics
Fabian Bussieweke, Tobias Herbst, Markus Lienkamp

In transportation and logistics, hub-and-spoke structures are commonly used to enhance system efficiency through capacity sharing. For full-truckload logistics, a hub structure can be advantageous since it facilitates the early adoption of autonomous driving technologies in road freight logistics. Driverless operation of trucks (SAE level 4) on highways is close to market readiness, allowing the automation of monotonous highway segments while leaving complex urban legs for human operators. With this approach, the current driver shortage in long-haul transportation can be addressed. This transfer hub system requires hubs near the highways where trailers can be exchanged between conventional and automated tractors.

When combining automation with the ongoing electrification of the logistics sector, hubs are an ideal choice for placing charging infrastructure. Since grid connection power is a major cost driver of charging infrastructure, the number and location of these hubs plays a pivotal role for the efficiency of the system.

To determine optimal hub locations for the transfer hub system, a mixed integer linear program formulation of the multiple allocation hub location problem is proposed. This formulation includes constraints regarding allowed detours, truck range, and grid connection at the locations. With the objective to find economically optimal hub locations, the problem is solved for Germany as a case study based on traffic flow data. To evaluate the effectiveness of the model, a comparison with the planned charging infrastructure locations for long-haul trucking ("Deutschlandnetz") is carried out. Additionally, a sensitivity analysis for different battery capacities is conducted.

3 - An Arc-Based Dynamic Discretization Discovery Approach for the Service Network Design Problem
Alexander Helber

Consolidation-based carriers transport shipments that are small compared to the capacity of the used vehicles. To enable cost-effective operations, they need to consolidate shipments. The Service Network Design Problem consists of determining the paths of shipments in the carriers network as well as the timing of the dispatches. Boland et al. (2017) proposed the Dynamic Discretization Discovery (DDD) framework to solve large scale instances of this problem to optimality by iteratively solving and refining a relaxed time-discretized model. We present a new relaxation for their DDD framework that uses an arc-based discretization of time and leads to significantly smaller models that can be solved faster. We also adapt some recent theoretical and algorithmic advances from the DDD literature to our relaxation. Computational experiments demonstrate that a DDD implementation based on our relaxation leads to models that are about five times smaller and solved twice as fast as those of a comparable node-based discretization approach for a hard set of instances from the literature.

4 - Hub location problem with a mixed green fleet
Okan Dukkanci, James Campbell, Achim Koberstein

This study presents a new hub location problem with a mixed fleet of vehicles, including diesel-based vehicles, electric vehicles, and unmanned aerial vehicles. Each vehicle type has a different cost structure, payload capacity, and traveling range. The objective function minimizes the sum of the recharging (or refuelling) cost, driver cost, fixed vehicle cost, and waiting cost for vehicles and drivers at recharging stations. While the transportation cost (including the recharging cost, driver cost, and vehicle cost) depends on the traveled distance, the recharging fee and waiting cost depend on the number of visits to recharging stations. We develop a mixed-integer linear programming formulation with preprocessing rules and also propose a relax-and-fix heuristic approach. The computational experiments are conducted over well-known CAB and TR data sets, and also a new German data set. The computational results evaluate the performance of the relax-and-fix heuristics and analyze the impact of using different mixed fleets, complete hub networks, different cost structures, and a hypothetical drone with a larger payload capacity and a longer flying range. Results show how the optimal fleet mix, in particular the use of electric vehicles and drones, and the optimal network vary around the world, as these depend on the geographic scope of the services, the distribution of nodes and arc lengths, and the relative costs for fuel (electricity or diesel) and labor.

■ TD-02

Thursday, 14:30-16:00 - Room: H4

Integer Programming II

Stream: Discrete and Combinatorial Optimization
Invited session
Chair: *Sven Mallach*

1 - Introducing clause-cuts to speed up MaxSAT problems in mixed integer linear programming
Max Engelhardt, Milan Adhikari, Jonasz Staszek, Alexander Martin

In this paper we introduce clause-cuts: linear inequalities obtained from clauses that are logically implied by a CNF formula, resembling strengthened no-good-cuts. With these cuts, we tighten mixed-integer linear programming (MILP) formulations of random weighted partial MAXSAT-problems, which have remained particularly challenging for MAXSAT-solvers. Our approach derives cuts from the set of variables that attain integral values at the LP relaxation, using SAT solvers to evaluate the feasibility of these partial assignments. When infeasible, these assignments are ruled out with clause-cuts which are further strengthened with the SAT-solver. Two separation algorithms are introduced, one that utilizes a SAT-oracle, and another that uses the clauses learned by a conflict driven clause learning (CDCL) SAT-solver. Experiments on SATLIB benchmarks demonstrate substantial performance gains - up to two orders of magnitude - compared to the general purpose MILP-solver Gurobi 12 and surpass the specialized MAXSAT-solver RC2. We explain the source of these gains and the limitations of standard MILP formulations in this context.

2 - Mixed-Integer Linear Programming Models for the Planar p-Median Problem: An Evaluation of Different Linear Approximation Techniques of Euclidean Distances
Fabian Wilschewski, Alf Kimms, Christin Münch

The planar p-median problem consists of locating a given number of facilities in the plane in order to minimize the sum of Euclidean distances from given demand points to its closest facility. As the problem has various applications, it has already received a lot of attention and many variants of the problem have been addressed. A major part of proposed solution methods are iterative approximation algorithms and heuristics. However, these methods are often closely related to a specific problem variant, whereby minor changes to the problem definition or new conditions may render an algorithm completely unusable or require a lot of effort to adapt it appropriately. In contrast, model-based approaches are typically more flexible, so that additional conditions can often be easily implemented. In order to utilize this advantage, we present different approximation techniques that enable the use of mixed-integer linear programming (MILP) model formulations. Moreover, we evaluate the performance of the proposed techniques in terms of solve time and approximation accuracy within the framework of MILP model formulations for the planar p-median problem. The results may also be valuable for related problems or other applications including Euclidean distances.

3 - A Lagrangian Decomposition Approach with Heuristic Search for Multi-Agent Path Planning in Moving Target Environments
Wataru Murata

Multi-agent path planning (MAPP) is integral to the fleet management of autonomous vehicles and robots across domains such as surveillance, search, and delivery. A key challenge in various applications lies in addressing the complex issue of moving targets, along with undefined terminal positions for agents, limited time availability, and continuous-valued delivery amounts. This study proposes a Lagrangian decomposition approach to solve a mixed integer second order cone programming (MISOCP) problem that incorporates these complexities. The problem is decomposed into subproblems for each agent by applying the Lagrangian relaxation technique. The proposed approach then iteratively performs subproblem optimization, feasible solution construction, and Lagrange multiplier update until a termination condition is met. A heuristic search is employed during the feasible solution construction to accelerate the convergence of the upper bound, leveraging the results from the subproblem optimization. Additionally, the Lagrange multipliers are initialized using a heuristic solution to obtain a tighter lower bound. Numerical experiments demonstrate that the proposed approach outperforms a direct method, highlighting its potential for solving complex MAPP problems.

4 - Integer Programming Formulations for the Target Visitation Problem - Revisited
Sven Mallach

The target visitation problem asks for a permutation (or tour) of target locations such that the difference between a reward expressing pairwise relative ordering preferences and the traveling distance is maximum. It can thus be seen as a combination of the traveling salesman problem and the linear ordering problem, or likewise as a generalization of the traveling salesman problem with precedences. In 2015, Hildenbrandt proposed according integer programming formulations along with polyhedral investigations. In this work, we extend and slightly revise some of these results, we highlight relations to betweenness and quadratic linear ordering problems, and we give some impressions about the computational performance obtained with the most promising integer programming models.

■ TD-03

Thursday, 14:30-16:00 - Room: H5

Workforce Scheduling and Routing

Stream: Project Management and Scheduling
Invited session
Chair: *Simon Emde*

1 - Optimization of Workforce Planning in Daycare Centers: Balancing Operational Needs and Legal Requirements
Bienvenu Bambi, Emeline Tenaud

This talk presents an industrial application for workforce planning in a network of daycare centers and animal care facilities. The schedules are optimized for a week and aim to plan the activities of several hundred employees, considering about ten different functions. Each employee has specific availability constraints, work hour limits, and role qualifications. The demand for each function is determined by legal requirements regarding staff-to-child ratios and operational needs. The problem is modeled with boolean decision variables representing employee-shift assignments, where shifts are generated based on minimum/maximum durations and time increments. The optimization model minimizes understaffing and overstaffing while respecting all operational constraints (legal requirements, employee work hour limits, and specific scheduling rules). This highly combinatorial optimization problem has been efficiently solved using Hexaly, a global optimization solver combining exact and heuristic methods. The solver provides optimal solutions within minutes for real-world instances. Based on this optimization model, a web application has been developed. A demonstration of this application will be presented during the talk.

2 - Solving the Rotating Workforce Scheduling Problem With Global Constraints

Tristan Becker

The Rotating Workforce Scheduling Problem (RWSP) is a central planning task in many industries, aiming to generate work schedules that repeat over a defined cycle while ensuring efficient staff deployment and providing employees with consistent work assignments. While compact formulations have proven highly effective for the RWSP, their inherent structure, which avoids an exhaustive representation of days, presents a significant challenge in modeling global constraints. These constraints apply to extended periods of the schedule and are highly relevant in real-world workforce scheduling. They ensure, e.g., a minimum number of free weekends within a multi-week window or a maximum number of specific duties across several weeks. Addressing this gap, we propose a new mathematical model that integrates various global constraints into a compact RWSP representation by augmenting a global constraint graph. Our computational experiments evaluate the performance of our compact modeling framework with global constraints against non-compact mathematical programming models. The results indicate that our compact modeling framework is able to account for complex global constraints while preserving the computational efficiency and inherent benefits of compact RWSP models. Furthermore, our compact model with global constraints greatly outperforms non-compact models, allowing for an efficient resolution of the RWSP with global constraints.

3 - The non-disjoint Clustered Traveling Salesperson Problem

Felix Weidinger, Kris Braekers

The talk is introducing the non-disjoint Clustered Traveling Salesperson Problem (ndCTSP). For the classical Clustered Traveling Salesperson Problem (CTSP) all vertices of a graph are assigned exactly one cluster. All vertices of the same cluster then need to be visited in direct succession before a subsequent cluster can be entered; therefore, nodes within each cluster as well as the clusters themselves need to be sequenced (see Chisman (1975): The clustered traveling salesman problem. Computers & Operations Research, 2(2), 115-119). For the ndCTSP, however, vertices can be assigned several clusters, of which not all need to be considered, i.e., activated, in a solution. As a consequence of the many-to-many relation, not all vertices of an activated cluster have to be visited contiguously, as they can be included into the tour later or might be already part of the tour via another cluster they belong to. Hereby, however, each cluster can be activated at most once and the tour has to be enclosed in activated clusters, i.e., the active cluster can only be switched in a vertex belonging to the previously and successively activated cluster. In the talk, two versions of ndCTSP are defined and analyzed regarding their problem specifications and complexity status. Different integer programs are introduced and compared in a computational study making use of off-the-shelf solver Gurobi. Finally, relations of the ndCTSP to other planning problems are detailed, positioning the ndCTSP as a generalization of planning problems from different domains, as, for example, warehousing.

4 - Scheduling and Routing the Pickup and Delivery of Furniture

Simon Emde, Shohre Zehtabian

Furniture retailers increasingly engage in the circular economy because many old furniture pieces are suitable for recycling or even reuse, while customers greatly appreciate collection services, reducing friction when purchasing new items. However, this poses particular challenges from a logistics perspective. For one, customers often replace old furniture with new, hence sales can be increased by offering collection services along with delivery. For another, because of the bulky nature of the merchandise, careful planning of deliveries and pickups is necessary because the vehicle capacity is easily exceeded. In this context, we present a multi-depot simultaneous pickup and delivery problem with time windows that considers selective pickups and seeks to minimize the lost rewards from failed pickups. We adopt a state-of-the-art routing solver from the literature to this problem, to design both a heuristic that integrates route and collection planning and a decomposition heuristic that routes first and plans pickups second. In a computational study on instances from the literature and based on realistic data, we show that strictly minimizing tour length can lead to a substantial amount of missed pickups. Moreover, we investigate the effects of time window management and fleet composition on logistics efficiency.

■ TD-04

Thursday, 14:30-16:00 - Room: H6

GOR Young Researchers Awards

Stream: PC Stream

Award Competition session

Chair: *Stefan Ruzika*

1 - Balancing resources for dynamic vehicle routing with stochastic customer requests

Ninja Scherr

We consider a service provider performing pre-planned service for initially known customers with a fleet of vehicles, e.g., parcel delivery. During execution, new dynamic service requests occur, e.g., for parcel pickup. The goal of the service provider is to serve as many dynamic requests as possible while ensuring service of all initial customers. The allocation of initial services impacts the potential of serving dynamic requests. An allocation aiming on a time-efficient initial routing leads to minimal overall workload regarding the initial solution but may congest some vehicles that are unable to serve additional requests along their routes. An even workload division is less efficient but grants all vehicles flexibility for additional services. In this paper, we investigate the balance between efficiency and flexibility. For the initial customers, we modify a routing algorithm to allow a shift between efficient initial routing and evenly balanced workloads. For effective dynamic decision making with respect to the dynamic requests, we present value function approximations with different feature sets capturing vehicle workload in different levels of detail. We show that sacrificing some initial routing efficiency in favor of a balanced vehicle workload is a key factor for a flexible integration of later customer requests that leads to an average improvement of 10.75%. Further, we show when explicitly depicting heterogeneity in the vehicle workload by features of the value function approximation provides benefits and that the best choice of features leads to an average improvement of 5.71% compared to the worst feature choice.

2 - Last mile delivery routing problem with some-day option

Stefan Voigt, Markus Frank, Heinrich Kuhn

The demand for fast deliveries in e-commerce places increasing pressure on logistics systems, driving up both costs and environmental impacts. This study explores a novel alternative: introducing a slower but more flexible delivery option termed some-day delivery. Unlike same-day services, some-day delivery guarantees arrival within a flexible timeframe, allowing logistics providers to better consolidate shipments, reduce total distance traveled, and optimize vehicle utilization. We first present insights from a consumer survey revealing that customers are generally willing to accept a slower delivery in particular when incentives are offered. These preferences vary by demographic factors such as age, gender, and environmental awareness. Building on these findings, we formulate a dynamic, stochastic last-mile delivery problem where orders arrive over time and customers can choose between delivery speeds. We propose a hybrid adaptive large neighborhood search (HALNS) to solve daily prize-collecting vehicle routing subproblems with time windows (PCVRPTW). Our method outperforms existing heuristics on PCVRPTW benchmark instances. Numerical experiments demonstrate that even modest customer adoption of some-day delivery can yield substantial benefits. A 10% shift in preference can reduce delivery costs by 3.9% and fleet size by 3.7%, all while maintaining customer satisfaction.

3 - Tropical Location Problems: A Robust Approach to Phylogenetic Consensus
Andrei Comăneci

How can we combine conflicting evolutionary trees into a meaningful summary? In evolutionary biology, phylogenetic trees represent hypotheses about species ancestry. But different datasets or inference methods often produce conflicting trees, and synthesizing them into a single, informative consensus tree is a challenging task. Traditional consensus methods tend to ignore features like branch lengths and are sensitive to rogue taxa — species whose positions vary wildly across trees.

In this talk, I present a new approach to this problem using ideas from tropical geometry — a mathematical framework with nonstandard arithmetic but strong geometric properties. We model trees as points in a tropical linear space and explore a class of distances whose balls are tropically convex. This allows us to study location problems where optimal solutions lie in the tropical convex hull of the inputs.

This framework leads to a broad class of tropically convex consensus methods with desirable properties: they incorporate branch lengths, are more robust to rogue taxa, and preserve key structural relationships between taxa present across input trees. These methods are mathematically principled, computationally efficient, and illustrate how geometric reasoning can support robust data summarization — offering new insights into the consensus problem in phylogenetics.

■ TD-05

Thursday, 14:30-16:00 - Room: H7

Multiobjective Optimization 3: Representations

Stream: Decision Theory and Multi-criteria Decision Making
Invited session
Chair: *Oliver Bachtler*

1 - A fast algorithm to find the optimal representation of the efficient set
Thomas Stidsen, Clemens Thielen

Most real-world planning problems are inherently multi-objective. Over the last decade, a number of more practically useful algorithms for multi-objective optimization have been proposed and are now available as open source code in Julia/JuMP. These algorithms can be applied to discrete multi-objective problems with up to six objectives.

Despite this success, multi-objective approaches still yield computational challenges: The computation requirements can be immense since often NP-hard problems have to be solved many times. Furthermore, the complete non-dominated set, the Pareto front, can be huge. Finding all the non-dominated points is, thus, often time consuming, and afterwards a decision maker may have to evaluate a large number of non-dominated points to identify the best trade-off. This work can also be time consuming.

An alternative is to find a representation of the full set of non-dominated points, i.e., a subset of the non-dominated points that represents the non-dominated set well in some sense. In this presentation, we present a novel bi-objective optimization algorithm for computing a representation of the non-dominated set without having to first compute the full non-dominated set.

2 - Representation of the Non-dominated Set by the Supported Non-dominated Points
Michael Stiglmayr, David Könen, Lara Löhken, Kathrin Klamroth

While multi-objective linear optimization problems only contain supported nondominated points, the nondominated point set of multi-objective combinatorial optimization problems, such as network optimization problems, also contain nonsupported nondominated points.

These points generally outnumber the supported ones and are more challenging to determine, as they cannot be obtained as optimal solutions of weighted sum problems with weights strictly greater than zero. We consider the set of supported and the set of extreme supported nondominated points as representations for the complete nondominated set. Various quality metrics, such as coverage error, hypervolume ratio, and epsilon-indicator, are used to analyze and compare the quality of these representations.

Multiple classes of network optimization problems are generated to evaluate the representations by the supported nondominated points. The results indicate that the supported nondominated points consistently provide high-quality representations, while considering only the extreme supported nondominated points may only yield sufficiently good representations in network optimization problems where the arc capacities are quite small.

3 - An adjacency-based algorithm for computing all extreme-supported efficient spanning trees
Oliver Bachtler, Felix Fritz, Stefan Ruzika

Generally, multi-criteria optimisation problems are solved exactly or approximated by solving a series of scalarisations, for example by dichotomic search. In this talk, we will take a different approach and compute the set of all extreme-supported non-dominated solutions of the bi-criteria minimum spanning tree problem by using a neighbourhood-based approach. We also look at the generalisation to matroids.

We call two spanning trees adjacent if they have all but one of their edges in common. Note that, with respect to this neighbourhood definition, neither the set of extreme-supported efficient nor the set of efficient spanning trees is connected. Additionally, while the set of supported efficient solutions is connected, it can be of exponential size. Nevertheless, we show how we can traverse the set of supported efficient solutions in such a way that all extreme-supported efficient solutions are found and only a polynomial number of supported efficient solutions are visited.

Finally, we note that the extreme-supported efficient solutions are a (2,1), (1,2)-approximation for general multi-criteria optimisation problems and briefly look at how we can transfer results from parametric optimisation to this setting.

■ TD-06

Thursday, 14:30-16:00 - Room: H9

Financial Reporting

Stream: Financial Management and Accounting
Invited session
Chair: *Matthias Amen*

1 - A quantitative approach to aggregating operating segments for the purposes of financial reporting under IFRS 8
Matthias Amen

IFRS 8 "Operating Segments" requires the grouping of operating segments into aggregated segments. A differentiated, aggregated presentation of assets and liabilities, income and expenses has to be reported separately for these reportable segments. A reportable segment should consist of one or more operating segments that are similar. Not all operating segments need to be aggregated into one reportable segment. The problem can therefore be characterised as a binary assignment similar to the Knapsack problem.

IFRS 8 defines sets of different requirements for the definition of reportable segments. The overall objective is up to the reporting company itself. To this end, we use a technical objective function that aims to minimise the dissimilarity inside reportable segments. By choosing different values for a weighting parameter in the formal objective function, we can generate solutions with a different number of reportable segments.

We formulate and solve the problem using AMPL and standard solvers. This also enables a discussion of IFRS 8 to improve future standard setting.

2 - The impact of deferred taxes on key business figures under IAS 12
Carolin Famulla

Deferred taxes are defined as expected future tax payments or refunds arising from temporary differences between the accounting and tax balance sheet, according to International Accounting Standard No. 12. As such, deferred taxes affect the comprehensive income and the equity with regard to the financial statement. According to the balance-sheet-oriented temporary-concept, deferred taxes relate to items recognized both inside and outside profit and loss. In addition, deferred taxes have an impact on different key business figures. Generally, this effect is temporary due to the compensatory nature of deferred taxes. But under certain conditions, deferred taxes can have a permanent effect on key business figures, such as the percentage of self-financing. This key figure is a percentage measure for the permanent distributable income as a proportion of equity. Considering accounting discretion, I have modelled the effect of deferred taxes recognized both inside and outside profit and loss on the self-financing ratio. The presented approach analyzes the impact of deferred taxes on the percentage of self-financing, particularly under which conditions the effect is temporary or permanent, and how deferred taxes influence the objective of maximizing the self-financing ratio.

3 - Accounting Conservatism and the Efficiency of Debt Contracts: A Real Option Approach
Stefan Kupfer

In this paper, I examine how accounting conservatism influences the efficiency of debt contracting from a dynamic perspective. Using a real options framework, I analyze how imprecise accounting information affects the timing of financial decisions and the total social loss resulting from management error. Debt contracts rely on such imperfect accounting signals, which can lead to errors in decision-making due to false alarms (inefficient early liquidations) or undue optimism (unjustified prolonged operation). Conservatism increases the likelihood of early loss recognition (false alarms) but reduces the risk of overstated performance. As a result, it affects the timing of actions triggered by accounting signals, potentially leading to liquidation of viable firms or the continuation of unprofitable ones. While prior literature provides theoretical arguments for both liberal and conservative accounting in maximizing welfare, it predominantly relies adopts static frameworks. I contribute by introducing a dynamic perspective. This approach yields novel insights as relatively late or early actions do influence the time value of the welfare effect discussed in the literature. Focusing on the tension between debt and equity holders, I derive the optimal liquidation timing and capital structures under varying levels of conservatism and characterize the resulting welfare effects.

4 - The Impact of Business Model Selection on Organizational Resilience in Times of Crisis
Vedant Sharma

With the increasing global uncertainties and crises, understanding how businesses can effectively respond and adapt towards them is more critical and necessary than ever. This systematic literature review investigates how the choices and innovations in business models contribute to organizational resilience during the disruptions, particularly during the recent events such as the COVID 19 pandemic and ongoing geopolitical disruptions. By synthesizing insights from dynamic capabilities theory to evolutionary economic theory, they have explained the framework of how firms build, adapt, and sustain resilience. This systematic review article finds that flexible business model design, supported by dynamic capabilities (e.g., sensing, seizing, and reconfiguring), enables organizations to rapidly and efficiently reconfigure resources to navigate through disruptions. We identify organization resilience as an emergent dynamic capability itself, continuously strengthened through improving the business models and experiential learning from crises. Theoretical implications include the understanding of resilience as an adaptable layered construct, closely linked to strategic innovation and dynamic capabilities. From the practical perspective, the findings suggest strategies for firms - especially small and medium enterprises (SMEs) in unstable environments to enhance resilience, such as continuously refining their business models and promoting an innovation-driven culture capable of proactively responding to uncertainty. This work contributes to both resilience literature and business model innovation research by providing valuable guidance for organizations operating in disruptive environments.

■ TD-08
Thursday, 14:30-16:00 - Room: H8

Human Factors and Strategic Tradeoffs in Emerging Technologies

Stream: Game Theory and Behavioral Management Science
Invited session
Chair: *Henrik Franke*

1 - The Narrow Focus in Negotiations: When Perceptions Matter More Than Value
Dylan Gellert, Nicolas Fugger, Andreas Fügener, Sebastian Schiffels

Modern supply chains thrive on collaboration, but determining each firm's value contribution remains difficult—especially for customized inputs where market prices fall short. While economic theory (e.g., the Shapley value) offers guidance on fair value allocation, real-world negotiations often diverge. Our research explores how buyers and suppliers negotiate under such conditions, particularly when switching partners is costly. We examine what parties focus on during procurement negotiations and what they might neglect. Do they account for the total value created by a deal, or narrowly focus on the supplier's perceived contribution? Using high-stakes field negotiations (Study 1) and a controlled experiment (Study 2), we show that parties often adopt a narrow focus, heavily influencing outcomes. Surprisingly, payoff-irrelevant cues—information that should have no rational impact—can shift perceptions and fairness judgments. Study 1 reveals that suppliers frequently receive less than their Shapley value contribution, illustrating real-world consequences of this narrow framing. Study 2 confirms these effects in a lab setting and establishes a causal role for payoff-irrelevant cues. Even in asymmetric power dynamics, both buyers and suppliers can use these cues to their advantage. We make two key contributions: (1) presenting robust evidence that payoff-irrelevant cues shape negotiation results, even in critical deals; and (2) demonstrating their causal impact through experimentation. For managers, this means that strategically designing such cues can guide negotiations—especially since parties often fail to consider the full value created. Recognizing this dynamic helps firms reach better outcomes in complex supply chain settings.

2 - Incentivization under Augmented Reality
David Wuttke, Mrunal Mohadikar

Incentivization in operations is constrained by the difficulty of monitoring worker effort, unions' demands for wage equality, and administrative friction. Digital technologies such as augmented reality (AR) enable fine-grained performance tracking, offering new ways to assess formative (process-based) rather than just summative (outcome-based) performance. This paper develops a game-theoretic model to examine when AR-enabled formative assessments can improve incentive alignment. We compare three contracts: wage-only, summative, and formative under varying degrees of agency problems, labor-market frictions, and administrative costs. In the absence of frictions, all contracts lead to the same outcome. However, the introduction of an agency problem immediately breaks this equivalence: wage-only contracts fail to elicit effort, whereas both summative and formative contracts remain effective and implement the first-best. When labor-market frictions require identical contracts and ensure that no worker is worse off, summative and formative contracts may still perform equally well—provided that workers' capabilities are similarly ranked across tasks. But when worker capabilities vary by task, formative contracts become strictly superior: they allow incentives to better match individual strengths. Administrative frictions can shift preferences back toward simpler contracts, depending on their cost. Our findings inform the design of incentive schemes in digitally enabled workplaces and clarify how AR facilitates novel contract structures that accommodate institutional constraints while enhancing performance.

3 - How Specialists and Generalists Complicate IoT Investments in Manufacturing: A Quasi-Field Experiment
Henrik Franke

Can a Tier-2 automotive supplier become more efficient using advanced IoT to enable workforce pooling on the shop floor? Surprisingly, no—but why? We analyze a naturally occurring field experiment based on 1,645,913 machine status reports and 2,533,323 completed work tasks over four years. While pooling is effective in principle, behavioral factors and worker preferences ultimately erode its potential efficiency gains. We distinguish the effects of worker roles and highlight a trade-off between IoT effectiveness and workplace equality.

■ TD-09

Thursday, 14:30-16:00 - Room: H15

Optimization in Energy Infrastructure Planning

Stream: Energy and Sustainability
Invited session
Chair: *Dominik Möst*

1 - Developing a multi-criteria model for sustainability assessment of regional energy systems
Caroline Andersen, Martin Schulwitz, Lars-Peter Lauven

The decarbonisation of energy systems will play a central role in achieving climate neutrality. Therefore, a comprehensive transformation of the energy system is needed and requires not only the deployment of new technologies (e.g. hydrogen production, renewable energies), but also the planning and adaptation of the necessary infrastructures for their implementation. The optimal design of energy infrastructures is influenced by many local factors, including the type of major industries in the area, existing infrastructure, and geographical conditions. Consequently, a new modelling tool is required that accounts for spatial interdependencies at a high resolution. The aim of this contribution is to propose a multi-criteria assessment model for integrated infrastructure planning. To demonstrate its potential, the model is applied to a case study in a German region, and the corresponding results are presented. By examining the impacts of energy systems on selected sustainability criteria within a specific region the model is designed to support decision-making and to accelerate the planning process. In accordance with the principles of sustainable development and the energy policy triangle, criteria such as affordability, security of supply and environmental compatibility are combined with spatial criteria, including land usage and bundling effects. These criteria are determined through the application of life cycle assessment (LCA) and spatial analysis, and are subsequently weighted using methods of multi-criteria decision analysis (MCDA). The model is developed and applied within the framework of the 'HydroNet' project funded by the German Federal Ministry of Economic Affairs and Climate Action.

2 - Charger Location Assessment and Utilization Prediction Using Cluster Analysis and Machine Learning - A case study in Germany
Nils Katzke, David Rößler-von Saß, Natalia Kliewer, Christian Hein

The shift to sustainable transportation makes the electrification of individual motorized travel crucial. However, adoption remains slow due to high vehicle costs and, more significantly, range limitations. To mitigate range anxiety, public charging infrastructure must be strategically planned to ensure high availability and demand orientation, allowing electric vehicles to meet travelers' needs as reliably as conventional vehicles. To support this goal, this study presents a data-driven approach to identifying critical charging locations based on multiple performance indicators. Feature selection techniques and clustering algorithms are applied to classify charging sites based on technological and contextual attributes. The analysis is based on charging data from Germany's public-funded infrastructure, provided by NOW GmbH. Our experiments explore various feature selection strategies and clustering methods to determine their effectiveness in identifying utilization patterns. Associations between cluster characteristics and observed utilization are evaluated to derive insights into charging behaviors. The results demonstrate the potential of clustering to inform charger utilization prediction and provide valuable implications for charging location management and policy development. This approach supports efficient infrastructure deployment and offers a framework for guiding future planning and incentivization strategies.

3 - Aggregator-Based Local Energy Markets and Congestion Management
Kai Hoth, Kathrin Fischer

In this work, a day-ahead process for a local energy market is developed, allowing aggregators to trade energy on behalf of communities of prosumer households. This process is based on a MILP model that optimizes an aggregator's decisions regarding the deployment of the households' various flexible energy resources while considering multiple trading options, including a local market. The day-ahead local market operates through iterative bidding phases, during which matching bids are fixed and local prices are adjusted according to supply and demand. The objective of these iterations is to incentivize high local trading volumes, thereby exploiting the potential for local energy exchange.

The process is applied in a case study with ten aggregators that manage a total of 111 households. Characteristic summer and winter days are selected to represent a range of external conditions. Furthermore, two distinct configurations for the assignment of households to aggregators are compared. The results show that both external conditions and aggregator configurations influence local trading potential, which is highest when aggregators are assigned dissimilar household configurations and external conditions result in a nearly balanced local energy supply and demand. Extreme conditions like high heating loads due to low ambient temperatures cause an imbalance between demand and supply that inhibits local trading.

Additional analyses explore market interventions through targeted price adjustments as a means of congestion management. Four intervention schemes are tested in multiple variants. The most effective of these schemes reduces power line overloads by approximately 8 %, demonstrating that local market interventions can support congestion management.

■ TD-10

Thursday, 14:30-16:00 - Room: H16

Order Picking

Stream: Supply Chain Management and Production
Invited session
Chair: *Martin Sauer*

1 - The costs of human-centric planning - a constraint programming approach for the AMR fleet in assisted order picking
Minqi Zhang, Eric Grosse, Simon Emde

Recent research has increasingly emphasized the integration of ergonomic considerations into industrial operational planning models. Despite this progress, many models continue to simplify realistic resource constraints to reduce computational complexity. This can significantly limit their practical applicability, particularly in environments involving human-robot collaboration. This study addresses this limitation through the scenario of AMR-assisted order picking (AOP). Human workers are responsible for item picking, while AMRs handle transport tasks. Incorporating human fatigue into the planning model has the potential to reduce long-term injury risks. Meanwhile, it raises concerns about both operational costs, such AMR-fleet size, and computational costs, such as model complexity. We propose two constraint programming (CP) models for AMR fleet planning, situated within a broader human-centric framework. The main modeling assumptions include the following: (i) orders, composed of multiple individual tasks, are assigned to AMRs as indivisible units; (ii) each AMR tour, which starts and ends at a central depot, is subject to a limited batch size; (iii) synchronization with human workflows is achieved by imposing strict arrival time windows at each task location, explicitly avoiding waiting time for humans. The planning problem, thus, inherits the computational challenges of typical task allocation and routing problems in logistics and warehousing. Computational experiments using IBM CP Optimizer and Google OR-Tools were conducted to evaluate the feasibility and efficiency of the proposed CP models. Additionally, we discuss how these models can be embedded into a more comprehensive human-centric AOP planning framework through logic-based Benders decomposition.

2 - An adaptive fix-and-optimize heuristic for solving the integrative zoning and item-to-zone assignment problem in the context of pick-and-pass systems
Regina Thelen, Ralf Gössinger

Pick-and-pass systems (P&PS) are zoned order picking systems in which each picker only works in one storage zone and each zone only comprises a sub-set of items. Hence, order-related containers are routed along a sequence of zones to be filled up with the items needed for order fulfillment. When designing a P&PS, two organizational questions need to be answered: How should the zones be formed and which item should be assigned to which zone? Since both problems are strongly interrelated, we developed a decision model that simultaneously determines zone size and item-to-zone assignment. A numerical pre-study revealed that an exact approach can only solve small prob-lem instances with reasonable computational effort. Since the computational ef-fort of the fix-and-optimize heuristic (FOH) is significantly lower, we expect that problem instances of realistic size can be solved in an acceptable time. Starting from an initial solution, FOH generates smaller sub-problems by iteratively fixing some decision variables, and applies a standard solver to obtain solutions. The best solution to the sub-problems is selected as the solution to the overall problem. In the basic FOH, the problem decomposition is done in advance of the solution process. In the intended paper, we introduce a new adaptive FOH that decomposes the problem before and during the solution process. This allows the search for better solutions to be controlled depending on the solutions found so far. To assess the performance of this approach, we develop FOH variants and conduct a full-factorial numerical study.

3 - Metaheuristics for the Order and Break Sequencing Problem under Energy Expenditure Considerations in Sequential Zone Picking Systems
Martin Sauer, Katja Schimmelpfeng

Zone picking refers to the partitioning of a warehouse picking area into non-overlapping zones, with each zone assigned to an order picker responsible for retrieving the corresponding parts of an order. In sequential zone picking, orders flow through these zones in a fixed-zone visitation sequence. While this system maintains a high pick rate, it also increases task repetitiveness, leading to significant levels of physical fatigue among order pickers and an increased risk of injuries.

To address this issue, we introduce the Sequential Zone Picking Systems Order and Break Sequencing Problem under Energy Expenditure (SZPOBS-EE). Our solution approach uses metaheuristic methods, like Variable Neighborhood Search or Parallel Tempering, to sequence orders and schedule breaks, balancing order throughput and physical fatigue. Through a numerical study, we benchmark our metaheuristics against a MIP.

■ TD-11

Thursday, 14:30-16:00 - Room: U2-200

Applications

Stream: Pricing and Revenue Management
Invited session
Chair: *Matthias Soppert*

1 - Dynamic Compensation Optimization for Occasional Driver Delivery
Kai Winheller, Rouven Schur, Matthias Soppert

Many brick-and-mortar retailers now complement their stores with home-delivery services, yet the last mile remains the most expensive link in the supply chain. A promising solution is to engage in-store customers as occasional drivers (ODs), who deliver online orders along their homeward routes. Previous research typically assumes that retailers deterministically know each customer's post-purchase destination and that ODs are always willing to execute a delivery once assigned—assumptions rarely met in practice.

We dispense with both assumptions. Instead, we model the destinations of ODs as stochastic, reflecting real-world uncertainty. Retailers can directly influence ODs' willingness to participate and their selection of delivery tasks by dynamically adjusting monetary incentives. We represent this decision environment as a finite-horizon Markov decision process. For a special one-dimensional (1D) case, we derive a closed-form optimal policy. Building upon this insight, we develop a decomposition-based algorithm that leverages the exact solution of the 1D case to heuristically address the more complex two-dimensional (2D) scenario.

2 - Ride-hailing networks with strategic drivers: The effects of driver wage policies and network characteristics on performance
Uta Mohring, Philipp Afèche, Andre Augusto Cire

When matching riders with drivers over a spatial network, ride-hailing platforms face spatial demand imbalances, which require driver repositioning to serve the total rider demand, and strategic drivers, who decide whether to participate in the platform and if so, whether and where to reposition. We study the effects of driver wage policies on drivers' decisions and the resulting equilibrium under decentralized repositioning and evaluate their effectiveness in achieving the centralized performance benchmark. We consider a stationary fluid model of a ride-hailing network in a game-theoretic framework with riders, drivers, and the platform. We characterize the steady-state system equilibrium under decentralized repositioning for various driver wage policies as well as how the effectiveness of driver wage policies depends on the interplay of demand imbalances, wage flexibility, and the congestion-sensitivity and spatial relations of travel times. More precisely: (i) We identify necessary and sufficient travel time conditions for equilibrium existence. (ii) We show that origin-dependent wage rates are sufficient to achieve the centrally optimal capacity level and platform profit while more limited wage flexibility yields idle driver inefficiencies. (iii) Our results indicate that decentralized repositioning yields an efficiency loss as the centrally optimal repositioning rates can generally not be implemented under decentralized repositioning, even with full wage flexibility. Our results provide novel insights into how key network operational and financial characteristics affect the efficiency loss of decentralized repositioning and managerial guidelines for the design of driver wage policies under decentralized repositioning.

3 - Pricing and Capacity Strategies in Cloud Procurement: An Economic Analysis of Multi-Cloud Decisions
Tarun Jain, Jishnu Hazra, Ram Gopal

Federal agencies frequently use reverse auctions to procure cloud infrastructure services from leading providers such as Amazon, Google, and Microsoft. While prior research has addressed operational aspects of cloud computing, the pricing dynamics in vendor selection under auction-based procurement remain underexplored. This study examines key strategic decisions, including the optimal number of cloud providers in bidding and the trade-off between public cloud procurement and private cloud investments.

Our findings suggest that higher cost heterogeneity among vendors results in fewer selected providers. Interestingly, such variation in pricing can either encourage or discourage private cloud investments. When the market has very few cloud providers, a private cloud strategy is more beneficial. In contrast, a highly competitive vendor landscape favors a public cloud approach. For markets with moderate competition, a hybrid cloud strategy is the most effective choice.

■ TD-12

Thursday, 14:30-16:00 - Room: H10

Scheduling in Healthcare I

Stream: Health Care Management
Invited session
Chair: *Daniela Guericke*

1 - Enhancing Fairness in Emergency Medical Services: Single- and Bi-Objective Model Formulations
Isabel Wiemer, Jutta Geldermann

The primary goal of emergency medical services (EMS) is to respond quickly and efficiently to emergencies within a given area. However, in regions with a heterogeneous demand distribution—such as urban, mixed, and rural areas—coverage levels can vary widely. To reduce inequalities in coverage, many approaches incorporate fairness as model objective when planning EMS locations. One common strategy is to focus on the least-covered area by maximizing its expected coverage. However, this approach does not directly address the coverage levels of the second, third, and subsequent least-covered areas, potentially leaving broader disparities unaddressed. Therefore, we propose explicitly considering not only the worst-covered area but also the second, third, and subsequent least-covered areas. Our goal is to enhance the average coverage level across the set p of worst-covered areas. To that end, we introduce a novel fairness objective and formulate a single-objective model. Additionally, we integrate this objective with expected coverage in a bi-objective model, utilizing the epsilon constraint method to balance fairness and overall coverage. To evaluate our fairness objective's applicability, we conduct a case study for the city of Duisburg, Germany, with real-world emergency data from three consecutive years. We analyze various sets p of the worst-covered areas and different epsilon values to evaluate individual coverage levels as well as overall expected coverage. Preliminary results indicate that our proposed fairness objective enhances the average coverage of the worst-served areas in Duisburg while maintaining a high level of overall efficiency.

2 - Joint Optimization of Short-Term and Long-Term Home Care Services
Asal Karimpour, Daniela Guericke, Amin Asadi, Erwin W. Hans

Joint Optimization of Short-Term and Long-Term Home Care Services

Asal Karimpour, Daniela Guericke, Amin Asadi, Erwin Hans

The demand for home care has increased over the past decades due to the aging population and the shift of some healthcare services from hospitals to homes. In response, home care providers must increasingly manage two types of care demand: short-term and long-term. Long-term care involves clients who require ongoing support, such as elderly patients with their activities of daily living. Here, the continuity of care (in this context, avoiding frequent nurse changes) is crucial to ensure client and nurse satisfaction. On the other hand, short-term care refers to temporary needs that last several weeks (e.g., follow-up on wound treatments of patients discharged from the hospital after surgery), where continuity of care is less critical. Our research addresses the complexity and potential conflicting objectives that arise from the integration of short-term and long-term care in nurse scheduling and client visit assignments. We propose a mixed-integer linear program that captures the mix of care types and investigates whether assigning dedicated nurses to short-term care is beneficial in terms of efficiency and continuity of care, or if a mixture of care types should be handled by a team of nurses. The model includes shift scheduling requirements based on working regulations such as working hours, break times, and nurse availability as well as client requirements. We present preliminary results based on realistic data from a home care organization.

3 - A hybrid solution approach for the Integrated Healthcare Timetabling Competition 2024
Daniela Guericke, Matthias Walter, Rolf van der Hulst, Asal Karimpour, Ieke Schrader

The Integrated Healthcare Timetabling Competition (IHTC) 2024 posed a planning problem relevant to the hospital sector. The IHTC considers four coupled scheduling problems in an integrated problem setting, since patient flow through the hospital creates dependencies between them. The scheduling problems are: 1) deciding the patients' admission day, 2) scheduling the patients' surgeries in operating theatres, 3) assigning patients to rooms, and 4) assigning nurses to rooms to care for the patients. These decisions must satisfy several hard and soft constraints. The objective function of the IHTC consists of weighted penalties for the eight soft constraints.

Since mixed-integer programming models for the entire problem are prohibitively large, we propose a hybrid solution approach utilizing mixed-integer programming, constraint programming, and simulated annealing. Our approach decomposes the planning into different phases and explores feasible solutions from previous phases in parallel to find solutions for the overall planning problem. During the presentation, we will discuss the relevant models and design decisions, as well as results from the competition instances and the insights we gained into future research directions while solving them. Our approach, which proved robust across different instance settings, ultimately placed among the finalists of the competition.

Thursday, 16:30-17:15

■ TE-01

Thursday, 16:30-17:15 - Room: Audimax

Semi-plenary talk de Kok

Stream: PC Stream
Semi-plenary session
Chair: *Rainer Kolisch*

1 - Forecasting, Lot Sizing, Safety Stocks and Empirical Validity
Ton de Kok

Over many decades the fields of forecasting, lot sizing and inventory management have developed in parallel. These fields are the foundation for today's planning systems as embedded in Advanced Planning and Scheduling (APS) systems. The field of forecasting has a very strong empirical basis, as its methodology is derived to a large extent from mathematical statistics. The field of inventory management is rooted in the mathematical analysis of stochastic processes. Lot sizing is a well-developed branch of combinatorial optimization and MILP. In text books on Operations Research and Operations Management, separate chapters are devoted to these fields. As the real-life problem concerns the use of forecasts, inventory control rules and lot sizing mechanisms for multiple items in a multi-echelon inventory system, heuristics have been implemented in APS systems. Typically, a wide range of forecasting methods are offered, some lot sizing heuristics, and basic safety stock formulas derived under some service measure assumption.

In this lecture we discuss the caveats of this pragmatic approach, typically resulting in a discrepancy between target customer service and actual customer service. We provide an explanation for this phenomenon and propose a framework under which under the assumption of linear holding and penalty costs, we can derive the optimal parameters of all end-item control policies with only two long-run simulations, irrespective of the forecasting method and lot sizing mechanisms. We discuss possible extensions to setting parameters for control of upstream items in the multi-item multi-echelon setting.

■ TE-02

Thursday, 16:30-17:15 - Room: H4

Semi-plenary talk Salman

Stream: PC Stream
Semi-plenary session
Chair: *Stefan Ruzika*

1 - Efficient and equitable relief aid allocation and distribution
Sibel Salman

In post-disaster response, relief items are delivered to disaster victims to meet immediate needs and alleviate suffering. At the initial stages of the disaster, it is important to allocate limited supplies equitably and ensure that they reach the people in need as soon as possible. We will present a study on planning vehicle routes from a distribution center to shelters while allocating limited relief supplies. To balance efficiency and equity, a bi-objective problem is defined. The objectives are to minimize a Gini-index-based measure of inequity in unsatisfied demand for fair distribution and to minimize total travel time for timely delivery. By deriving mathematical properties of the optimal solution, we introduce valid inequalities and design an algorithm for optimal delivery allocations given feasible vehicle routes. A branch-and-price (B&P) algorithm is developed to solve the problem efficiently. Computational tests on realistic datasets show that the B&P algorithm significantly outperforms commercial MIP solvers. Our bi-objective approach reduces aid distribution inequity by 34% without compromising efficiency.

■ TE-05

Thursday, 16:30-17:15 - Room: H7

Semi-plenary talk Uchoa

Stream: PC Stream
Semi-plenary session
Chair: *Michael Römer*

1 - Optimizing with Column Generation
Eduardo Uchoa

Column Generation (CG) is a technique to solve Linear Programs with a very large number of variables. Instead of explicitly evaluating reduced costs, variables are dynamically generated by solving auxiliary optimization problems known as pricing subproblems. CG is one of the major optimization techniques, being also effective in integer programming, in algorithms like Branch-and-Price and Branch-Cut-and-Price. It has been successfully applied to many types of vehicle routing, cutting and packing, airline planning, timetabling, crew scheduling, graph coloring, clustering, lot sizing, and machine scheduling, among other problems. The talk provides an overview of the CG. The central question explored is: under what circumstances are CG-based algorithms likely to outperform other existing methods? The discussion draws on material from the recent book "Optimizing with Column Generation: advanced Branch-Cut-and-Price Algorithms (Part I)" available at https://optimizingwithcolumngeneration.github.io.

Thursday, 17:15-18:45

■ TF-01

Thursday, 17:15-18:45 - Room: Audimax

GOR Annual Meeting

Stream: PC Stream
Invited session
Chair: *Jutta Geldermann [GOR President]*

Friday, 8:45-10:15

■ FA-01

Friday, 8:45-10:15 - Room: Audimax

Railway Optimization

Stream: Mobility, Transportation, and Traffic
Invited session
Chair: *Hanno Schülldorf*

1 - Improving Scalability in Flat Yard Shunting Optimization: Refining Graph-Based Exploration in the HEROS Algorithm
Felix Rauschert, Pascal Kerschke

Efficient operation of industrial railways and freight transport networks relies heavily on optimizing shunting processes within flat yards. Our shunting algorithm, HEROS, employs a multi-stage approach tailored specifically for this purpose. The core of HEROS is an effective combination of exploration and exploitation of a graph-based representation of the solution space. Initially, a deterministic opening heuristic sets a preliminary path within the graph, establishing a baseline solution. Subsequently, the exploration phase incrementally extends this graph by introducing new edges and nodes, representing additional shunting operations and yard states. During the exploitation phase, HEROS focuses on discovering new paths within this expanded graph to enhance the objective value. The cycle of exploration and exploitation continues until termination criteria are met, consistently refining the best-known solution from the last exploitation phase.

Previous studies have demonstrated HEROS' strong performance, particularly in smaller yards, highlighting robustness and reliability in optimization. However, as problem size increases, the rate of improvement decreases. To address this, our current investigation focuses on refining the graph creation process and enhancing the network structure. Drawing from these insights, we aim to enhance the algorithm's exploration phase, thereby improving scalability for larger instances that involve more tracks and longer trains.

2 - A network flow model for multimodal freight transport incorporating the attractiveness of public rail sidings
Henning Preis, Daniel Haalboom, Uwe Höppner, Nikola Bešinović

Multimodal freight transport offers significant potential for shifting freight flows from road to rail. A key requirement for this shift is the availability of attractive access points, such as rail sidings, that facilitate the efficient transshipment of goods. The current research project "Starke Ladestelle für den Güterumschlag", funded by the German Centre for Rail Traffic Research (DZSF), focuses on evaluating and improving public access points for rail freight. This paper presents an extended network flow model for multimodal transport. It optimizes freight flows within a given infrastructure network using transport relations of different modes. It thus supports alternative routing decisions — with or without the use of rail freight transportation. In particular, the model incorporates attractiveness parameters of rail access points, including centrality, handling capabilities, average waiting times, service frequency, and connectivity to hub networks. The functionality of the approach is demonstrated on realistic instances based on data from Germany's 2030 freight transport forecast, solved using CPLEX. Initial evaluations highlight how the attractiveness of access points affects modal shift potential. Finally, the paper discusses the model's potential and identifies areas for further research within the "Starke Ladestelle für den Güterumschlag" project.

3 - Exploring possibilities of quantum computing for real-time traffic management in railway operations
Alexander Schuler, Nikola Bešinović

The demand for rail transport is expected to increase due to higher mobility needs and shifts in transport policy. This will lead to a higher capacity utilization of the existing network and therefore disturbances will become more frequent. To minimize the impact of these disturbances, dispatchers work on real-time traffic management. Their task is to adjust the timetable in order to resolve the resulting conflicts. Since time to find high quality solutions is limited, developing a computer-based optimization method to assist dispatchers has the potential to significantly increase the efficiency of rail transport. In large and dense railway networks this a challenging task with high computational complexity. Quantum computing represents a possible research direction, as it can offer advantages over classical computing due to its unique properties. This paper provides an introduction to the topic, by summarizing the key principles of quantum computing. Furthermore, it aims to identify the challenges and opportunities of using quantum computing for real-time traffic management in railway operations. For this purpose, the paper reviews existing approaches that use quantum computing in railway operations and other related fields. Finally, several further research directions are identified, ranging from detailed benchmarking to the development of new algorithms.

■ FA-02

Friday, 8:45-10:15 - Room: H4

Scheduling & Packing

Stream: Discrete and Combinatorial Optimization
Invited session
Chair: *Sigrid Knust*

1 - Multi-objective optimisation of the Hearing Scheduling Problem in the Court of Law
Ieke Schrader, Erwin W. Hans, Marco Schutten

The Dutch Judicial system faces efficiency challenges due to limited resources and increasing case disposition times. Tactical allocation of resources (e.g., by solving the Hearing Scheduling Problem (HSP)) reduces the severity of the efficiency problems. The HSP is concerned with scheduling hearing blocks over time and allocating resources (e.g., staff members and courtrooms) to these hearing blocks. A hearing block is a capacity reservation for a specific case type; multiple cases are assigned to one hearing block, which is done at the operational level. Decision-making is under broad limitations, such as staff member capacities, staff member skills and desk activity requirements. In practice, a planner considers the stakeholders' conflicting interests (i.e., justice seekers, system owners and staff members) while constructing a hearing block schedule. Optimising the number of hearing blocks may result in a schedule that performs poorly from a staff member's perspective. Hence, we propose a multi-objective mixed integer linear program that balances the stakeholders' interests by incorporating the workload for staff members, the spread of hearing block types and the total number of hearing blocks into the objective. During the conference, we will present the results of this approach. Our contribution is twofold. First, we formulate two objectives that measure the workload balance for a staff member and spread the hearing block types over the scheduling period in the judicial system. Second, we execute a scenario analysis in which we assess the impact of the importance of the objectives on the generated schedule.

2 - Friends, Not Enemies: Exploring Synergy Types Between Complementary MIP Models for Large-Scale Instances with an Application to RCPSP
Mohamed Ibrahim, Taieb Mellouli

Mixed integer programming (MIP) is a powerful framework for solving complex optimization problems. One such problem is the Resource Constraint Project Scheduling Problem (RCPSP) which schedules activities in a project while respecting the precedence relations and resources limitations. Multiple MIP formulations have been proposed for RCPSP, including the Continuous Flow (CF) formulation, which models resource usage as a continuous flow between activities, and the Discrete Time (DT) formulation, which uses time-indexed variables to represent activity start times and resource usage directly. One model excels at representing the resource consumption while the other excels at representing the time relations. However, each model alone performs poorly in comparison to heuristic and other excat methods like constraint programming. In this work, we explore how we can find synergy between different MIP models to achieve a performance not achieved by individual models. We show how solution properties obtained by the CF model can be used to infer more fine grained properties, and how those properties can be passed to the DT model to prune and model and improve it significantly. We then show how experimental results on standard data instances demonstrate the gains in solving time. We conclude by analysis of this approach and discuss how it may be generalized to other classes of combinatorial optimization problems.

3 - Heuristics for Variable Cost and Size Cluster Vector Bin Packing (VCSCVBP)
Laura Wolf, Sabrina Klos, Stefan Nickel

Vector bin packing, a multidimensional extension of the bin packing problem, involves packing a set of d-dimensional vectors, each representing the resource requirements of an item, into a d-dimensional vector representing the available bin resources. Motivated by the increasing demand for computing resources and the need for efficient capacity planning for cloud infrastructure, we present a model for vector bin packing with bins of variable sizes organized into clusters, where costs are incurred for utilizing clusters (VCSCVBP). The novelty here lies in the cluster structure of bins. We propose and evaluate several heuristics to address this problem, considering both homogeneous cluster structures (a single bin type per cluster) as well as heterogeneous structures (multiple bin types per cluster). Computational experiments demonstrate significant runtime improvements with only minor deviations from the best solutions found by the solver.

4 - Scheduling sports tournaments with two court types
Melissa Koch, Sigrid Knust, Xuan Thanh Le

Balanced tournament designs are a well-studied topic in sports league scheduling, particularly with regard to assigning courts to matches in a fair and uniform way. Usually, every court is treated uniquely. In this talk, we introduce a novel variant of the problem where courts of two different types are considered.

Two consecutive matches of a player on the same court type, are called a "court type repetition". Our objective is to construct a schedule for a single round-robin tournament that minimizes the total number of court type repetitions.

After outlining fundamental observations, we present efficient construction methods that yield optimal solutions in various settings. We start with schedules based on the canonical 1-factorization and demonstrate that better solutions can be achieved using arbitrary factorizations.

■ FA-03

Friday, 8:45-10:15 - Room: H5

Algorithms and Applications

Stream: Project Management and Scheduling
Invited session
Chair: *Max Deppert*

1 - Assessing the Relationships Between Digital Transformation and Dynamic Capabilities in the Construction Industry
Navodi Wijayarathne, Indra Gunawan, Frank Schultmann

The construction industry, as a key player in the project-based sector, is a significant contributor to the global economy, accounting for approximately 13% of the world's GDP. This study examines the relationships between Digital Transformation (DT) and Dynamic Capabilities (DC) in the construction industry. Existing literature has established a strong correlation between DT and DC; however, this correlation has rarely been explored in the construction sector. The thematic analysis of past literature highlights the leading role of DC in enabling effective navigation of DT. The findings imply the importance of DT as a mediator to foster DC during turbulent environments. Furthermore, the study examines how digital technologies, such as Building Information Modelling (BIM), Internet of Things (IoT), and Artificial Intelligence (AI), enhance resilience and strategic capabilities. The conceptual framework developed based on the thematic analysis is proposed for validation through hypothesis testing using Structural Equation Modelling (SEM). Data collection will happen through a structured survey questionnaire evaluating the construction professionals. The study intends to validate the relationships between DC and DT and the mediating role of DT. SEM is used to test the strengths and significance of both direct and mediating effects. Finally, the study plans to offer theoretical contributions by empirically validating the relationship between DT and DC in the construction industry. Simultaneously, it aims to provide practical insights for construction professionals to enhance resilience by leveraging digital adoptions through core components of DC: sensing opportunities, seizing innovations and reconfiguring resources.

2 - A Neural Decoder for Scheduling Problems with Complex Side Constraints
Maziyar Khadivi, Kevin Tierney, Homayoun Najjaran

Neural combinatorial optimization (NCO) has emerged as a promising approach for addressing NP-hard combinatorial optimization problems, such as routing, scheduling, and graph-based optimization. However, existing NCO methods struggle with real-world applications, particularly when dealing with complex side constraints that are difficult to represent compactly and when a masking mechanism is insufficient to enforce feasibility. The existing literature has yet to adequately address scenarios where deep neural networks (DNNs) must explicitly manage intricate operational constraints essential for solution feasibility and practical industrial implementations. To bridge this gap, we introduce a hybrid method that integrates a DNN with a heuristic decoder. Our DNN learns to optimally sequence a set of tasks, which are passed to the decoder, constructing the solution subject to the problem constraints. We validate the proposed method on the parallel machines scheduling problem with additional resources (PMSPR), a common problem in the manufacturing and service sectors, requiring the optimal assignment of jobs to machines supervised by limited additional resources. Derived from an industrial case study of a food processing plant, our PMSPR formulation accounts for operational constraints such as job release times, due dates, and machine eligibility. Compared to conventional operations research methods, including (meta)heuristics and exact solvers, our proposed approach helps reduce solving time. It enables real-time optimization in stochastic environments by rapidly inferring multiple scenarios to support ad hoc decisions under operational uncertainty.

3 - Two-machine open shop with limited storage space
Mateusz Dokowicz, Joanna Berlińska

We study makespan minimization in a two-machine open shop with limited storage space. In order to be processed, each job requires a given amount of storage capacity, which is allocated as soon as its first operation begins, and released only after the completion of its second operation. Thus, the storage space is used by the job not only during the execution of its operations, but also in the interval between completing the first and starting the second operation. This distinguishes our problem from open shop scheduling with resource constraints studied in the existing literature. The storage space available in the system is limited, which means that a job may start being processed only if sufficient capacity is available. The goal is to determine time intervals for executing all operations so as to minimize the maximum completion time. We show that the problem is strongly NP-hard and formulate it as an integer linear program. Heuristic algorithms are proposed and their performance is analyzed in a series of computational experiments.

Acknowledgement: The research of the first author was supported by Adam Mickiewicz University, Poznan, under the Excellence Initiative - Research University Study@research grant 161/34/UAM/0041.

4 - The Power of Duality: Response Time Analysis meets Integer Programming
Max Deppert, Klaus Jansen

We study a mutually enriching connection between response time analysis in real-time systems and the mixing set problem. Thereby generalizing over known results we present a new approach to the computation of response times in fixed-priority uniprocessor real-time scheduling. We even allow that the tasks are delayed by some period-constrained release jitter. By studying a dual problem formulation of the decision problem as an integer linear program we show that worst-case response times can be computed by algorithmically exploiting a conditional reduction to an instance of the mixing set problem.

In the important case of harmonic periods our new technique admits a near-quadratic algorithm to the exact computation of worst-case response times. We show that generally, a smaller utilization leads to more efficient algorithms even in fixed-priority scheduling. Worst-case response times can be understood as least fixed points to non-trivial fixed point equations and as such, our approach may also be used to solve suitable fixed point problems. Furthermore, we show that our technique can be reversed to solve the mixing set problem by computing worst-case response times to associated real-time scheduling task systems. Finally, we also apply our optimization technique to solve 4-block integer programs with simple objective functions.

■ FA-04

Friday, 8:45-10:15 - Room: H6

Dynamics of the Firm

Stream: Continuous and Global Optimization
Invited session
Chair: *Andrea Seidl*

1 - Investment under Uncertainty in a Durable Good Market

Herbert Dawid, Peter M. Kort, Xingang Wen

We consider a monopolistic firm that decides on the timing and production capacity for introducing a durable good into a market characterized by consumer heterogeneity and demand uncertainty. We show that when consumers are less heterogeneous, the firm should invest later, i.e. wait for product attractiveness to grow to a sufficiently high level, in a large production capacity. In case consumers are very heterogeneous, the firm should invest early in a small production capacity. In the latter case, selling the durable good in small quantities enables the firm to price discriminate over time, generating a high payoff. Whether an increase in consumer heterogeneity has a positive, negative or U-shaped impact on the value of the firm's investment opportunity depends on the relationship between trend and volatility of the dynamics of product attractiveness. The fact that an increase in consumer heterogeneity may have a positive effect on the firm value distinguishes the durable goods case from market settings with non-durable products.

2 - Capacity expansion investment under financing constraint

Luoyuan Gan, Xingang Wen, Herbert Dawid

This research studies a monopoly firm's timing and size decision to invest in a partially substitute product under demand uncertainty and financing constraint. We assume the investment cost is financed by the instantaneous profit of the old product. Then the financing constraint is binding , in case the investment size is bounded from above. The optimal investment decision balance the revenue effect and cannibalization effect. Although the new product generates additional revenue (revenue effect), it substitutes the old product and reduces revenues from the old product (cannibalization effect). We find that 1) The optimal investment size increases (decreases) with the old product output when the constraint is binding (non-binding). For relatively high levels of demand uncertainty, the optimal investment threshold is U-shaped with respect to the old product output, i.e., a trade-off outcome between the revenue and the cannibalization effects of the new investment that generates additional revenues but reduces revenues of the old product. 2) For a given old product output, the financing constraint is only binding for intermediate levels of demand uncertainty. Otherwise, the constraint is not binding because the optimal investment is either early with small costs (under low uncertainty), or so late that the instantaneous profit from the old product is sufficiently high (under high uncertainty).

3 - Dynamic pricing when consumption develops habit and/or satiation: farsighted vs myopic customers

Peter Kort, Gustav Feichtinger, Andrea Seidl, Franz Wirl, Stefan Wrzaczek

This paper examines monopolistic dynamic pricing strategies in the presence of customer habit formation and/or satiation. We find that penetration pricing is optimal when habit formation dominates, whereas satiation leads to the optimality of skimming pricing. Furthermore, we show that the optimal pricing strategy depends on whether customers are myopic or farsighted. With habit formation, both the firm and farsighted customers have an incentive to increase short-term consumption, as this enhances habit formation, ultimately boosting future demand and consumption utility. The firm capitalizes on this increased short-term demand by setting a higher price compared to when customers are myopic. Conversely, under satiation, the dynamics reverse, i.e., farsighted customers have less incentive to consume. In response, the firm lowers the price to mitigate demand reduction compared to the case of myopic customers.

4 - The Role of Learning in Technology Adoption

Andrea Seidl, Richard Hartl, Peter Kort

In a world where technology is rapidly evolving, learning is an integral part of staying competitive. However, learning is costly in the sense that one not only must spend money on learning material, tuition, etc., but it requires time that one could proactively use for earning money.

The present paper presents and analyses a two-stage model where a decision maker must decide about continuous investments into a knowledge stock with respect to a new technology. Before technology adoption the decision maker has to accumulate sufficient knowledge so that when the new technology is introduced, it can be operated in an effective and efficient manner. In the present paper, we will examine the timing of technology adoption and analyze the impact of learning by doing. Furthermore, we will discuss the occurrence and implications of history-dependent solutions.

■ FA-05

Friday, 8:45-10:15 - Room: H7

Multiobjective Optimization 4: Complex Systems, Scalarizations, and Related Problems

Stream: Decision Theory and Multi-criteria Decision Making
Invited session
Chair: *Stephanie Riedmüller*

1 - Integrated optimization of multi-objective sequential processes

Jonas Hürter, Anita Schöbel, Philine Schiewe

Complex optimization problems are often decomposed as sequential processes of n stages: Firstly, a group of variables x1 is chosen optimally for a problem P1, then x1 is used to determine the feasible set of a subsequent problem P2(x1) for which an optimal solution x2 is chosen. Problem P3(x1, x2) depends on x1 and x2 and determines the variables x3 and so forth; up to a final problem Pn(x1, ..., x(n-1)). This approach is a heuristic for the optimization of a corresponding integrated problem. Sequential processes and their integrated counterparts have been considered in the literature in the single-objective setting. Here, both the stages Pi of the sequential solution process and the integrated problem have only one objective function each. In this talk we extend the framework of sequential processes and the corresponding integrated problem to the multi-objective context, where the sequential stages can have multiple objectives and the integrated problem considers all sequential objectives. We show that all solutions of such a process are always weakly efficient and identify conditions for them being (strictly) efficient. We also investigate lexicographic solutions and use such a process for deriving a cutting plane algorithm. We demonstrate the setting with regard to the sequential planning process in public transport.

2 - Solving block-structured Integer programs with a single (soft) coupling constraint using Multi-Objectivization

Mark Lyngesen, Kathrin Klamroth, Britta Efkes

We seek to solve block-structured integer programs with a single coupling constraint by interpreting the coupling constraint as a second objective. This reformulation results in an additively-separable bi-objective optimization problem with a solution set which contains the optimal solution to the original problem. The resulting bi-objective problem is harder to solve. We therefore propose ways of directing the search for nondominated solutions to only require solutions mapping to a predefined region of interest. This approach allows us to use decomposition methods while also providing the decision maker with a set of alternative 'interesting' solutions.

3 - Modern Algorithms in Old Literature: What Can Multi-Objective Optimization Learn from Parametric Optimization?

Levin Nemesch, Stefan Ruzika, Clemens Thielen, Alina Wittmann

In multi-objective optimization, the goal is to optimize several, often conflicting, objectives at once. Instead of one single optimal solution, a whole set of efficient solutions is usually needed to achieve this. In parametric optimization, the goal is to optimize a problem that depends on one or more parameters. Again, solving a parametric optimization problem requires finding a set of solutions.

For many applications, the perspectives of multi-objective optimization and parametric optimization are inherently interwoven. Throughout the literature, similar strategies appear in each field. Surprisingly, however, literature from one is often unaware of literature from the other. Instead, approaches have been developed independently from each other several times. In many cases, strategies used in parametric optimization predate the ones used in multi-objective optimization by decades.

In this talk, we highlight parallel developments of algorithms in parametric and multi-objective optimization. Exemplary, we look at algorithms for the so-called weight set decomposition. The purpose of this talk is two-fold: First, we want to highlight some results that are rather unknown in modern literature, but deserve to be better known, as they can be seen as precursors to modern algorithms. Second, our talk should motivate researchers in all fields to be aware of fields with similar settings to theirs, such as parametric optimization, robust optimization, computational geometry and others for multi-objective optimization.

4 - Warm-Starting Strategies in Scalarization Methods for Multi-Objective Optimization
Stephanie Riedmüller, Janina Zittel, Thorsten Koch

We explore how warm-starting strategies can be integrated into scalarization-based approaches for multi-objective optimization in mathematical programming. Scalarization methods - particularly the weighted sum and epsilon-constraint methods - remain widely used classical techniques to compute Pareto-optimal solutions in applied settings. They are favored due to their algorithmic simplicity and broad applicability across continuous and integer programs with an arbitrary number of objectives. Scalarization methods are not only used as standalone tools but also serve as the foundation for more advanced and specialized algorithms. While warm-starting has been applied in this context before, a systematic methodology and analysis remain lacking. We address this gap by providing a theoretical characterization of warm-starting within scalarization methods. Central to this analysis is the sequencing of subproblems, which significantly influences warm-start efficiency. However, optimizing the order of subproblems to maximize warm-start efficiency can conflict with alternative criteria, such as the early identification of infeasible regions. We quantify these trade-offs through an extensive computational study.

■ FA-06
Friday, 8:45-10:15 - Room: H9

Risk Management

Stream: Financial Management and Accounting
Invited session
Chair: *Michael H. Breitner*
Chair: *Elmar Lukas*

1 - OR Meets Accounting: An MIP Formulation for the Item-Instrument Matching Decisions in Fair Value Hedging
Sinan Gürel, Ahmet Yüksel

Uncertainties, such as the interest rate and currency fluctuations, can pose risks to the financial assets of companies. The companies can hedge these risks by purchasing contracts that exchange the value of financial assets and swap their risks with the counterparts. Hedge accounting is a method that represents the hedging activities of a company in its financial statements and shows how the company manages its risks. It helps to reveal the core business operations' performance without interference from the macroeconomic conditions. The increased transparency helps investors to make more accurate decisions about the company. In this study, we consider a fair value hedging activity that requires a company, in each accounting period, to recalculate the fair values of both the hedged items and the hedging instruments. Based on these calculations, the company must rematch the items and instruments to maintain a relationship between their notional amounts, maturities, and fair values as required by the accounting standards. If a company holds numerous financial assets, such as a bank's loan portfolio, alongside many hedge instruments, matching these under the complex constraints of accounting standards becomes computationally demanding. This burden may even prevent firms from utilizing hedge accounting. In this study, we first demonstrate that we can formulate the matching decisions between hedge items and instruments as a mixed-integer program. Then, we present the computational performance of the commercial and open-source solvers on the model.

2 - Harnessing Accounting Data for Profitability Forecasts and Robust Portfolio Construction
Lukas Benjamin Heidbrink

Forecasting the financial performance of companies and markets is the subject matter of a variety of research papers. Measuring the accuracy of forecasts, however, does not take the level of profitability into account. Rather, it measures the predictability of profitability. This is why accuracy is considered a measure of robustness. Typically, accruals are known to increase risk and decrease reliability. Particularly, discretionary accruals cause lower forecasting ability. As such, the proposed model maximizes earnings yield while restricting the level of discretionary accruals, as well as short-term and long-term out-of-sample forecasting errors, resulting in a robust, low-risk portfolio that is highly predictable. Limiting the iterative forecasting error of future operating cash flows induces robustness, and limiting the share of discretionary accruals in profit reduces overall risk. With a slight modification, this model also allows for the identification of natural hedging strategies, in accordance with IFRS regulations. Given a company's financial assets and liabilities, the model identifies suitable shares for a macro-hedge, minimizing downside risk in the company's portfolio.

3 - Set-valued expectiles for ordered data analysis
Thi Khanh Linh Ha, Andreas H. Hamel

Expectile regions-like depth regions in general-capture the idea of centrality of multivariate distributions. If an order relation is present for the values of random vectors and a decision maker is interested in dominant/best points with respect to this order, centrality is not a useful concept. Therefore, cone expectile sets are introduced which depend on a vector preorder generated by a convex cone. This provides a way of describing and clustering a multivariate distribution/data cloud with respect to an order relation. Fundamental properties of cone expectiles are established including dual representations of both expectile regions and cone expectile sets. It is shown that set-valued sublinear risk measures can be constructed from cone expectile sets in the same way as in the univariate case. Inverse functions of cone expectiles are defined which should be considered as ranking functions related to the initial order relation rather than as depth functions. Finally, expectile orders for random vectors are introduced and characterized via expectile ranking functions.

4 - Determining the optimal time to purchase emission rights under uncertainty of the carbon dioxide price
Anna Uhrmeister

The awareness of climate change and the corresponding need for climate protection have become omnipresent for companies nowadays. In 2005, the European Commission established the European Union Emissions Trading Scheme (EU-ETS), in order to mitigate the effects of anthropogenic climate change and render them more predictable. From 2027, as a result of the so-called Green Deal, energy-intensive industries will in general be continue to be supported by free subsidies, but these will be massively reduced for sectors affected by the Carbon Border Adjustment Mechanism (CBAM). The ramifications for companies are still uncertain. Along with the implementation of the EU-ETS, companies are faced with the challenge of making decisions on the purchase of European Emission Allowances (EUA's). The study aims to provide an overview of the range of strategies a company is faced with. Subsequently, a selection of possible scenarios is analyzed e.g. the optimum time of purchase, considering capital commitment costs. Furthermore, the uncertainty caused by fluctuations in EUA's prices are considered.

■ FA-08
Friday, 8:45-10:15 - Room: H8

Game Theory and Strategic Behavior in Real-World Systems

Stream: Game Theory and Behavioral Management Science
Invited session
Chair: *Lukas Graf*

1 - Externalities in vaccination queues
Hamed Jalali, Ata Jalili Marand

Vaccination queues have been empirically shown to significantly influence individuals' decisions to seek vaccination. A substantial body of evidence highlights that long waiting times are among the primary factors contributing to low vaccination rates. While many studies modeling strategic behavior in vaccine supply chains use utility theory to capture individuals' decision-making processes, they often overlook the critical role of waiting time in shaping these decisions. In this paper, we model a game between a social planner, who seeks to maximize social welfare, and self-interested individuals, who aim to optimize their waiting-time-sensitive utilities. As in classical vaccination games, the social planner must address positive externalities: individuals tend to free ride, benefiting from reduced infection risk due to others' vaccinations without considering the broader public health impact of their own. Our model further introduces negative externalities: individuals also neglect the additional waiting time their presence imposes on others. We show that when vaccination capacity is limited or individuals are highly sensitive to waiting, unregulated demand for vaccination —absent any intervention by the social planner—can exceed the socially optimal level due to these negative externalities. In such cases, we compute a vaccination fee to align individual behavior with the social optimum. Conversely, when capacity is abundant or individuals are more tolerant of waiting, demand may fall short of the socially optimal level due to positive externalities, and we derive the incentive required to close this gap. Finally, we investigate the potential of priority queues to mitigate both externalities and provide guidance on their optimal design.

2 - Re-thinking exponential reward structures for esports tournaments - A game-theoretic approach
Friederike Paetz, Mahmood Pedram

Nowadays, (competitive) video gaming constitutes a US$180 billion industry with esports being the most rapidly growing aspect. Esports tournament organizers compete for audience and the easiest way to attract a large audience is by expanding the prize pool. A higher prize pool attracts top players, which attracts more audience. Beside the absolute prize pool, the reward structure is a key determinant for top players to enter the tournament. Hence, tournament organizers must assess the best split of the prize pool to the best players in the tournament. So far, exponential reward structures are commonly used, but there is no evidence of its optimality under varying experimental factors, e.g., heterogeneous skills of players, switching opportunities of players between tournaments.

We tackle this issue by analyzing the optimality of varying reward structures of two competing tournaments by considering heterogeneous skills of players and, therefore, different preferences of players towards varying reward structures, e.g., winner-takes-it-all, exponential design, linear design and logarithmic design. Using a game-theoretic model, "we show that in a tournament of approximately equally skilled players a linear reward structure is best, while the existence of a clear best player leads to an exponential design. Furthermore, we conduct a simulation-based framework, that relies on random utility theory and considers players' opportunity to switch between tournaments. We found that smaller tournaments should favor exponential reward structures while larger tournaments should favor more linear designs.

We conclude that the common practice of exponential reward structures should be rethought by tournament organizers.

3 - Are System Optimal Dynamic Flows Implementable by Tolls?
Lukas Graf, Tobias Harks, Julian Schwarz

In two seminal papers by Fleischer, Jain and Mahdian and Karakostas and Kolliopulos presented at FOCS 2004, it was shown that system optimal static flows can always be implemented by tolls. That is, there exist tolls on the edges such that the given flow becomes a Wardrop equilibrium. This result holds even for the case of multiple commodities with heterogeneous value-of-time sensitivities. For the much more complex setting of dynamic flows, we recently identified necessary and sufficient conditions for such flows over time to be implementable by time dependent edge tolls. However, whether system optimal dynamic flows are among those implementable flows is far from obvious.

We now consider this question of implementability of system optimal flows for a general dynamic flow model involving multiple commodities with individual source-sink pairs, fixed inflow rates and heterogeneous valuations of travel time and money spent. We present both a positive and a, perhaps surprising, negative result: For the negative result, we provide a network with multiple source and sink pairs in which under the Vickrey queuing model no system optimal flow is implementable - even if all users value travel times and spent money the same. Our counter-example even shows that the ratio of the achievable equilibrium travel times by using tolls and the system optimal travel times can be unbounded. For the single-source, single-sink case, we show that if the traversal time functions are suitably well-behaved (as is the case, for example, in the Vickrey queuing model), any system optimal flow is implementable.

■ FA-09

Friday, 8:45-10:15 - Room: H15

Renewable gases and supply chains

Stream: Energy and Sustainability
Invited session
Chair: *Dominik Möst*
Chair: *Frank Meisel*

1 - Designing Sustainable Supply Chains for Importing Renewable Energy Carriers
Mohammad Zardoshti Zadeh Yadi, Jörn Meyer, Grit Walther

The transition towards climate neutrality necessitates large-scale production of renewable energy carriers. However, spatial disconnects between renewable energy production in resource-rich regions and utilization in resource-deficit regions require establishing supply networks for long-distance transport of renewable energy carriers (RECs). To ensure the sustainable development of such supply networks, achieving economic viability, environmental efficiency, and energy security is crucial. We develop a multi-objective, mixed-integer, quadratic optimization model to design a supply network for the import of RECs that incorporates strategic decisions on locations, resource allocation, and infrastructure for conversion, transportation, and reconversion of RECs. We evaluate economic, environmental, and energy security aspects by minimizing the three objective functions of net present cost, greenhouse gas (GHG) emissions, and supply concentration of the REC supply network. The optimization model is implemented in Python and solved using Gurobi's quadratic solver. To assess the trade-offs between objective functions, we construct the Pareto frontier of non-dominated solutions using the augmented ϵ-constraint method. We demonstrate the applicability of the model through a case study examining the import of RECs from high-potential renewable energy regions to Europe. Our results show that, relative to the cost-optimal solution, the concentration-optimal solution results in about 88% lower supply concentration at 194% higher cost, while the GHG-optimal solution results in about 13% lower emissions at 182% higher cost. These trade-offs highlight the importance of balanced solutions for sustainable REC import strategies supporting Europe's transition to climate neutrality.

2 - Multi-objective Utility Optimization for Green Hydrogen Supply Chain Design
Frank Meisel, Louis Vincent Sroka

Many countries plan to import green hydrogen to make their economy more sustainable. However, selecting suitable sourcing partners and import routes involves complex trade-offs across economic, environmental, technological, and social dimensions. Research, therefore, highlights the need for multi-objective and multi-decision maker frameworks in hydrogen supply chain planning. In this presentation, we propose a mathematical optimization model designed to support decision makers in identifying the optimal green hydrogen import option based on individual preferences. The model evaluates direct import options from single exporters as well as more complex import networks involving multiple source regions. It integrates a multi-objective utility function composed of weighted and normalized values, including cost, emissions, social acceptance, technological efficiency, technology readiness, network complexity, and resilience. Normalization and thus comparability are achieved through benchmark values derived from the optimal import options of each criterion in isolation. By adjusting the weights, the model adapts to the priorities of different stakeholders, offering a flexible and transparent decision-support tool. Computational results include the identification of robust import options under varying stakeholder preferences and scenarios, as well as insights into trade-offs between criteria such as cost and resilience. The results show how diversified import networks can enhance resilience at the expense of higher network complexity, and under what preference profiles direct imports might remain the preferred option. These findings can support strategic decision-making and the formulation of effective policies for green hydrogen import infrastructure.

3 - Optimizing Biogas Transport Logistics with restrictions on nutrient redistribution
Nils-Hassan Quttineh, Roozbeh Feiz, Karin Tonderski

World instability in late years have demonstrated vulnerability in global supply chains, emphasizing the need for robust systems to ensure continuous supply of energy and food. Anaerobic digestion has emerged as a key technology in addressing these challenges, and as a result, ambitious biomethane production goals have been set within the EU. By converting low-grade biomass, such as manure and agricultural residues, into biomethane and nutrient-rich digestate, biogas plants contribute simultaneously to renewable energy generation and nutrient recycling. But like any other large-scale bioenergy generation, they rely on extensive transportation of biomass across the landscape.

Using a MILP model, we investigate how biogas plants can sustainably and cost-efficiently expand their production considering spatial variability of biomass supply and regional demand for nutrients. We use geospatial databases to map biomass availability (manure types, green residues, etc.), nutrient demand based on crop data, and road network databases to find accurate transportation distances and transportation costs.

The area of interest is discretized into 5 km x 5 km grid cells. The MILP model has constraints for limited supply of substrates in each grid, as well as maximum demands for nutrients N (nitrogen) and P (phosphorus) in order to avoid eutrophication. At the biogas plant, constraints are needed to guarantee a feasible substrate mixture in order for the plant to run properly. The objective function consists of transportation costs, both for collecting substrates and for redistribution of the biomass digestate. Other costs considered are purchasing costs of substrates and processing costs at the biogas plant.

4 - Don't let your breaks go to waste: The Waste-Performance-Tradeoff-Problem
Lennart Zey, Dirk Briskorn

In e-commerce warehouses, automated packaging machines are utilized in the final processing stages to efficiently pack customer orders. In this context, decision-makers in planning and procurement must balance conflicting objectives: optimizing carton sizes to reduce packaging waste while simultaneously managing the increased operational complexity and performance losses associated with a more diverse range of packaging options. In this paper, we examine so-called blocking machines, where multiple packaging devices are arranged in sequence, each equipped with a specific carton size. Incoming customer orders are transferred to the devices via a conveyor belt and can only be processed by devices with appropriately sized cartons. We introduce the resulting optimization problem, which involves selecting a set of carton sizes, assigning customer orders to these devices, and sequencing the orders. We analyze the computational complexity and present an exact dynamic programming approach that runs in polynomial time. Our method allows to analyze the tradeoff between waste generation and packaging speed. We demonstrate that our approach efficiently finds optimal solutions for real-world instances and provide further insights into the impact of different carton selection strategies.

■ FA-10

Friday, 8:45-10:15 - Room: H16

Network Design

Stream: Supply Chain Management and Production
Invited session
Chair: *Julia Erdmann*
Chair: *Tristan Becker*

1 - Uncapacitated Facility Location Problem for Drone-Based Intermodal Distribution Networks
Asrat Mekonnen Gobachew, Stefan Lier

The rise of drone-based logistics is transforming last-mile delivery, necessitating new facility location models that account for unique operational constraints of drones. This research proposes a hybrid approach to identify potential locations for micro-hubs and intermediate hubs within an intermodal drone delivery network. The network consists of a central warehouse that supplies micro-hubs using trucks, while drones handle last-mile deliveries to customers. To address the challenge of continuous facility location without predefined candidate sites, DBSCAN clustering is integrated with an uncapacitated facility location model. Clustering serves as a preprocessing step to identify initial micro-hub candidate locations based on customer distribution, reducing computational complexity. These candidate locations are then refined through optimization that assigns customers to the nearest feasible facility within drone range, applying penalties for unassigned locations. For customers beyond drone range, intermediate hubs are introduced at regular intervals to ensure service coverage. Infeasible facility sites, such as those located in water bodies or restricted zones, are relocated to nearby viable alternatives. A case study utilizing real-world data from two logistics providers demonstrates full customer coverage and validates the effectiveness of the proposed model. The framework supports strategic planning for scalable, drone-integrated logistics networks. Future work will focus on incorporating capacity constraints, dynamic routing, and multi-objective optimization to enhance sustainability and operational realism.

2 - The Value of Reliability in Modular Production Network Design
Lea Raubuch, Stefan Lier, Tristan Becker

Technical systems are subject to disruptions, and production units may consequently experience failures over time. In this context, a key advantage of modular production systems is their ability to compensate for disruptions by relocating the remaining operational units between established facilities in the short term. However, existing approaches to modular production network design have neglected the impact of such disruptions. To address this gap, we extend the Capacitated Reliable Facility Location Problem (CRFLP) to the context of modular production. We introduce two mathematical formulations: a facility-indexed and a module-indexed approach. The module-indexed formulation generalizes the CRFLP and represents the scenario space with a significantly lower number of scenarios compared to the standard model, provided an upper bound is imposed on the number of open facilities. Both formulations minimize total network costs while ensuring demand fulfillment, allowing for external procurement at a penalty cost. We propose a two-stage stochastic optimization framework. In the first stage, facility locations and modular production unit allocations are determined. In the second stage, production units may be relocated among open facilities, and customer demand may be reassigned accordingly. Given the combinatorial complexity and exponential growth of the scenario space, we apply Sample Average Approximation for our computational experiments. Our analysis evaluates the impact of relocation flexibility and reliability on modular production network cost. The results indicate that incorporating stochasticity into the selection of modular production facilities improves the performance of the network for moderate and high failure probabilities.

3 - Optimizing Biomass Collection under Uncertain Quality: A Stochastic Routing Approach with Decentralized Adaptability
Julia Erdmann

Biological residues hold substantial potential for bioenergy production, but their variable quality challenges stable yields and profitability. Biorefineries must plan biomass collection with limited quality information, relying on rough on-site assessments based on visual inspection by collectors during pickup. This inherent uncertainty complicates decision-making and affects operational efficiency. Motivated by this practical context, we propose a novel hybrid two-stage stochastic framework that captures the dynamic and decentralized nature of biomass logistics with flexible on-site adaptations. The problem is formulated as a profit-maximizing, multi-vehicle Traveling Purchaser Problem, accounting for biomass quality factors. In the first stage, supplier selection, routing, and collected quantities are optimized across multiple quality scenarios to generate a robust collection plan. In the second, simulation-based stage, drivers follow pre-planned routes and make rule-based on-site adjustments, such as rejecting low-quality biomass or increasing collected quantities within vehicle capacity. We evaluate our hybrid stochastic approach against a deterministic model variant using Monte Carlo simulations across variable quality scenarios. Results show that anticipatory, scenario-based planning combined with on-site flexibility consistently delivers more resilient outcomes compared to deterministic planning. Our framework is the first biomass logistics model to incorporate driver-level autonomy in quantity decisions. By bridging centralized operational planning with field-level adaptability, it offers practical decision support for quality-sensitive biomass collection under uncertainty.

■ FA-12

Friday, 8:45-10:15 - Room: H10

Scheduling in Healthcare II

Stream: Health Care Management
Invited session
Chair: *Jens Brunner*

1 - Outpatient appointment scheduling

Tibor Dulai, Gombás Veronika, Péter Scsibrán, Ágnes Vathy-Fogarassy

Outpatient appointment scheduling plays a critical role in ensuring timely access to care for patients and efficient utilization of healthcare resources. The problem becomes especially complex when multiple examination types must be scheduled for a single patient, each requiring assignment to time slots of qualified practitioners. While exact methods can solve this problem optimally, when the number of available time slots is small, their computational time grows rapidly with the problem size. Heuristic approaches can provide high-quality solutions within reasonable time. A domain-adapted genetic algorithm was developed to address the outpatient scheduling problem, taking into account the requirements of both patients and practitioners. A custom solution encoding is used, and the mutation genetic operator was developed to best fit the objective function. The effectiveness of the algorithm was evaluated both on different calendar configurations and on real data from Hungarian healthcare providers. Our results show that the developed genetic algorithm provides optimal or near-optimal results faster, compared to the applied exact method in the case of medium- and big-sized problems.

This work was supported by the 2020-1.1.2-PIACI-KFI-2020-00045 ('Collaborative Hospital Information Platform,' Development of a process-oriented medical system to support inpatient specialized care) project with the support provided by the Ministry of Culture and Innovation of Hungary from the National Research, Development and Innovation Fund. Project no. MEC_R 149182 has been implemented with the support provided by the Ministry of Culture and Innovation of Hungary from the National Research, Development and Innovation Fund, financed under the MEC_24 funding scheme.

2 - Optimizing Inpatient Postoperative Therapy Scheduling: Integrating AI-assisted Physical Therapy

Lorenz Wagner, Christian Jost, Sebastian Schiffels, Jens Brunner

At hospitals, receiving postoperative therapy is essential after lung cancer, cardiac, and orthopedic surgeries. However, the limited availability of specialized therapists often delays treatments and prolongs hospital stays. To address this challenge, companies offer visual AI assisted therapy to supplement in-person therapy. This creates new opportunities for the efficient scheduling of therapy sessions. Our research offers a comprehensive optimization model to derive therapy schedules that integrate traditional in-person and AI-assisted therapy. The proposed mathematical model minimizes the Length of Stay, contingent upon the treatment effectiveness of combined therapy and AI sessions, intending to optimize therapist resource utilization. To efficiently solve large-scale scheduling instances, we introduce a Column Generation heuristic. Computational experiments using real-world data from our practice partner, Breathment, demonstrate that our approach can effectively complement traditional physiotherapy, providing a scalable solution to address therapist shortages while maintaining high-quality patient care. This research contributes to healthcare operations research by offering practical solutions for hospitals to optimize their physiotherapy services through technology integration.

3 - A VRP approach to schedule nursing care professionals to training positions in practical education during their apprenticeship

Corinna Oppitz, Sebastian Kraul, Jens Brunner

Due to the demographic change, the need for medical care and care in general will rise in Germany. On the other hand, the gap between the demand and the supply of health care professionals is predicted to increase. This underlines the importance of making the care professions more attractive, especially for future trainees. To address these challenges, the vocational educations for nurses, paediatric nurses and geriatric nurses were reformed and are currently joined in one generalist vocational education. This vocational education covers nursing care for people of all ages in various fields of care. Although this makes the planning of practical education challenging, as institutions of various fields of care and their capacities need to be respected, it is frequently done manually. We develop a model to generate a schedule, which assigns trainees to training positions in the different fields of care as stated in the training and examination regulations. In order to use and determine the capacities of the involved institutions as best as possible, the objective is to minimize the number of training positions needed. We model the problem as a heterogeneous vehicle routing problem with time windows. Due to the complexity and the size of the problem, a tailored column generation approach is developed. We discuss our model and present preliminary computational results on artificially generated data.

4 - Consultant Routing Problem: A Multi-Depot Vehicle Routing Problem with Multiple Visits and Trips

Jens Brunner, Johannes Uhrmann, Christian Jost, Sebastian Schiffels

We study a real-world vehicle routing problem faced by pharmaceutical companies, where medical consultants regularly travel to meet physicians for product consultations. Given the long and frequent travel distances, as well as rising transportation costs, these visits represent a significant expense for companies. Therefore, efficient planning of tours is essential. In practice, however, this is often done manually, typically by the consultants themselves. Working together with a practice partner, our goal is to analyze the potential of centralized planning using mathematical optimization. Several key constraints must be considered: (1) all tours must start and end at the consultant's home; (2) physicians may be visited multiple times within the planning period; (3) each planning period has a maximum number of working days, with each working day corresponding to a single tour. We model the problem as a multi-depot vehicle routing problem with multiple visits and multiple trips to accurately capture these requirements. The objective is to minimize the total travel time of all consultants while adhering to various operational constraints, such as fair distribution of visits, compliance with working hours, and the strengthening of client relationships. Due to the high complexity of the resulting model, we propose a decomposition-based solution approach using column generation, in which the pricing subproblems are formulated as time-constrained shortest path problems. To efficiently solve these subproblems, we explore several variants of the labeling algorithm, and present preliminary computational results that illustrate their comparative performance and practical viability.

Friday, 10:45-11:30

■ FB-01

Friday, 10:45-11:30 - Room: Audimax

Semi-plenary talk Rudová

Stream: PC Stream
Semi-plenary session
Chair: *Kevin Tierney*

1 - Real-world Routing and Planning in Logistics
Hana Rudová

Efficient logistics planning and routing are critical for modern transportation and warehouse management, where complex constraints and large-scale operations must be handled effectively. This talk will explore various routing and planning problems, including classical and rich vehicle routing problems, order picking, and team orienteering. We will discuss real-world, large-scale problems in transportation and warehouse planning, highlighting the challenges that arise in practice.

Various algorithmic approaches have been developed for solving large-scale routing and related planning problems, ranging from classical heuristics to advanced metaheuristics. We will provide an overview of key methodologies, including large neighborhood search, evolutionary mechanisms, and hybrid techniques, emphasizing their efficiency and adaptability in different logistical settings. Beyond traditional optimization, handling uncertainties is essential for robust logistics planning. We will examine how uncertainties such as the amount of transported load and temporal aspects impact routing solutions and discuss strategies for adapting and extending existing efficient approaches.

■ FB-02

Friday, 10:45-11:30 - Room: H4

Semi-plenary talk Fransoo

Stream: PC Stream
Semi-plenary session
Chair: *Marc Goerigk*

1 - Operations for policymaking
Jan C. Fransoo

Traditionally, operations (management) research has very much focused on changing operations to impact performance. With the growth in attention on the UN Sustainable Development Goals in our research, the definition of performance has been widened to include outcomes related to climate change, poverty, and labor conditions. However, in terms of actors this primarily focuses on operational actors, such as companies, NGOs, or hospitals. This has separated us from economics research that typically studies policy questions by governments and governmental institutions such as central banks. In this presentation, I will argue that as operations management researchers, we have an opportunity and a need to think more explicitly about the policy impact of our research, with an angle that distinguishes us from the traditional angles chosen in economics research.

■ FB-05

Friday, 10:45-11:30 - Room: H7

Semi-plenary talk López-Ibáñez

Stream: PC Stream
Semi-plenary session
Chair: *Michael Römer*

1 - The Future of Optimisation Research
Manuel López-Ibáñez

This talk examines some recent, and not so recent, trends in optimisation research in its broadest sense, that is, including both exact and heuristic methods. Despite impressive achievements in solving a diverse range of increasingly complex problems, there are a few practices that hinder progress in our field. Among them, poor empirical reproducibility, lack of novelty, and questionable research practices. At the same time, developments in surrogate models, reinforcement learning and Large Language Models (LLMs) are already disrupting classical optimisation approaches. These developments bring also many opportunities to push forward the state of the art in optimisation research. Similarly, the success of general-purpose commercial heuristic solvers presents new challenges to the research field, while also raising the bar for impactful research. Finally, the talk will highlight several relatively under-explored directions in optimisation research, including reflective optimisers and "human-in-the-optimisation-loop".

■ FB-09

Friday, 10:45-11:30 - Room: H15

Hexaly Lecture

Stream: PC Stream
Sponsored session
Chair: *Léa Blaise*

1 - Hexaly, a new kind of global optimization solver
Léa Blaise

Hexaly Optimizer is a new kind of global optimization solver. Its modeling interface is nonlinear and set-oriented. In a sense, Hexaly APIs unify and extend modeling concepts from mixed-linear programming, nonlinear programming, and constraint programming. Under the hood, Hexaly combines various exact and heuristic optimization methods, such as branch-and-bound, automatic Dantzig-Wolfe reformulation, column and row generation, propagation methods, local search, direct search, and surrogate modeling techniques.

Regarding performance benchmarks, Hexaly distinguishes itself against the leading solvers in the market, like Gurobi, IBM Cplex, and Google OR Tools, by delivering fast and scalable solutions to Routing, Scheduling, Packing, Clustering, and Location problems.

This talk will introduce our set-based modeling formalism and show its scalability for large instances. We will then explore how the solver can use this formalism to automatically use state-of-the-art resolution techniques from the exact and heuristic fields.

Friday, 11:45-13:15

■ FC-01

Friday, 11:45-13:15 - Room: Audimax

Plenary Talk Ruiz & Closing Event

Stream: PC Stream
Plenary session
Chair: *Jutta Geldermann [GOR President]*
Chair: *Matthias Amen*

1 - From Academia to Industry: The Case for Simplified Operations Research in Amazon Web Services
Rubén Ruiz

This talk explores the critical divide between academic Operations Research and its application in complex industrial environments, with a focus on Amazon Web Services. In these settings, unprecedented scale and rapid delivery are not just desirable—they're imperative. While academia often pursues algorithmic complexity and theoretical optimality, the industrial landscape demands a paradigm shift towards pragmatism and agility. Both aspects are neglected and often ignored in academia where complexity and problem-specific knowledge are sought for and valued over practical applications.

We confront the reality of multi-objective problems, soft constraints, and the ever-shifting sands of business requirements that characterize real-world scenarios. These factors necessitate a radical rethinking of traditional OR approaches.

Our proposition is bold yet practical: embrace heuristic solvers and simplified modeling techniques that prioritize speed, adaptability, and ease of implementation. This approach is particularly crucial when dealing with estimated input data, where the pursuit of mathematical optimality may be not just impractical, but potentially misleading.

Through a series of compelling case studies—ranging from classical routing and scheduling problems to large-scale virtual machine placement in Amazon EC2—we demonstrate the power of pragmatic methods in addressing real-world challenges. These examples illustrate how seemingly "suboptimal" solutions can yield robust, maintainable, and highly effective outcomes that balance performance with operational efficiency.

Ultimately, this presentation challenges the OR community to reconsider the true meaning of optimality in industrial contexts. We argue that a marginal optimality gap is a small price to pay for the immense benefits of enhanced flexibility, reduced operational complexity, and the ability to swiftly adapt to changing business requirements. This talk aims to spark a dialogue about aligning academic research with the pressing needs of industry, potentially reshaping the future of OR in practice.

Analytics, Data Science, and Forecasting

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Track(s): 6

Artificial Intelligence, Machine Learning and Optimization

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Track(s): 12

Continuous and Global Optimization

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Track(s): 4

Decision Theory and Multi-criteria Decision Making

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Track(s): 5

Discrete and Combinatorial Optimization

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Track(s): 2 4

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Track(s): 10

Energy and Sustainability

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Track(s): 3 9

Financial Management and Accounting

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Track(s): 6

Game Theory and Behavioral Management Science

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Track(s): 8

Health Care Management

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Track(s): 8 12

Heuristics, Metaheuristics and Matheuristics

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Track(s): 11

Mobility, Transportation, and Traffic

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Track(s): 1 10

OR in Developing Countries

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Track(s): 11

PC Stream

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Pricing and Revenue Management

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Track(s): 11

Project Management and Scheduling

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Simulation and Quantum Computing

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Track(s): 7

Software for Operations Research

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Track(s): 9

Supply Chain Management and Production

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Track(s): 10

Technical Operations Research

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Track(s): 7

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