SCIENTIFIC PROGRAM

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OPERATIONS RESEARCH 2024

OR 2024

MUNICH

DATA, LEARNING, AND
OPTIMIZATION

SEPTEMBER
3 - 6, 2024

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STREAM OVERVIEW

Stream	Stream Numbers	Rooms
Building: Theresianum		
Analytics and Data	03	0606
AI, ML, and Optimization	02	0602, 0606
Applications in Management, Engineering and the Sciences	14	2607
Decision Theory and MCDM	12	2601
Energy, Finance, and Sustainability	18 - 20	0601, 0670 ZG, 1601
Game Theory, Behavior, and Mathematical Economics	11	2609
Software for OR	13	2605
Building: Nordgebäude		
Mobility, Transport, and Traffic	21 - 23	N1070, N1080, N1090
Building: Wirtschaftswissenschaften		
Continuous and Global Optimization	08	Z538
Discrete and Combinatorial Optimization	06 - 07	Z534, Z536
Pricing and Revenue Management	09	Z532
SCM, Production, and Scheduling	15 - 17	0534, 0540, 0544
Service Operations and Healthcare	10	0514
Building: Wienandsbau		
Optimization under Uncertainty	04 - 05	2999, 3999

	WB Wednesday 11.00 – 12.00	WC Wednesday 13.00 – 14.30	WE Wednesday 16.30 – 18.00	TA Thursday 8.30 – 10.00	TC Thursday 11.30 – 13.00	TD Thursday 14.00 – 15.30	FA Friday 8.30 – 9.30	FC Friday 10.45 – 12.15
Theresianum								
03 Analytics and Data 0606	WB 03: Applications of Analytics	WC 03: Advances in Machine Learning	WE 03: Forecasting	TA 03: Explainability and Interpretability 1	TC 03: Explainability and Interpretability 2	TD 03: Data-Driven Optimization		FC 03: Data Analytics
02 AI, ML, and Optimization 0602	WB 02: Learning for Optimization 1	WC 02: Learning for Optimization 2	WE 02: Metaparameter-Sensitivity, Heuristics and Data Integration in Machine Learning	TA 02: Learning for Optimization 3	TC 02: Optimization for Learning	TD 02: Machine Learning for Supply Chain Optimization	FA 02: Equilibrium Learning	FC 02: Statistics and Machine Learning
14 Applications in Management, Engineering, and the Sciences 2607		WC 14: Optimization and Modeling in Production	WE 14: Decision Support and Heuristics	TA 14: Optimization in Construction and Additive Manufacturing	TC 14: Innovation and Technology in Industry	TD 14: Model Lifecycle[1]		FC 14: Optimization in Sports and Work-Rest
12 Decision Theory and MCDM 2601		WC 12: Robust and Stochastic MCDM	WE 12: Applications in MCDM	TA 12: MCDM in Transportation and Supply Networks	TC 12: Multi-criteria Optimization	TD 12: MCDM Innovations	FA 12: Data Envelopment Analysis	FC 12: Approximations for MCDM

[1] Belongs to Stream 13

	WB Wednesday 11.00 – 12.00	**WC** Wednesday 13.00 – 14.30	**WE** Wednesday 16.30 – 18.00	**TA** Thursday 8.30 – 10.00	**TC** Thursday 11.30 – 13.00	**TD** Thursday 14.00 – 15.30	**FA** Friday 8.30 – 9.30	**FC** Friday 10.45 – 12.15
18, 19, 20 Energy, Finance, and Sustainability **18** 0601	WB 18: Heating Networks	WC 18: Optimisation and Incentive Mechanisms for Load Applications in Electricity Systems	WE 18: Energy Flexibility	TA 18: Green Transition Scenarios	TC 18: Energy Flexibility 2	TD 18: Electricity Market Modelling		FC 18: Renewable Operations
19 1601	WB 19: Multi-criteria Decision Making	WC 19: Near Optimal Solutions and Open Frameworks	WE 19: Multi-Criteria, Multi-Objective Decision-Support in Energy and Sustainability	TA 19: Decomposition Methods for Large-scale Energy Planning	TC 19: Industry, Water and Urbanisation	TD 19: Decomposition Approaches	FA 19: Game Theoretical Approaches	
20 ZG 0670		WC 20: Climate Uncertainty and Risks	WE 20: Natural Language Processing		TC 20: Sustainable Operations Management	TD 20: Portfolio Optimisation and Risk Assessment		FC 20: Capital Costs and Investments
11 Game Theory, Behavior, and Mathematical Economics 2609	WB 11: Behavioral Decisions 1	WC 11: Behavioral Decisions 2	WE 11: Human-AI Interface	TA 11: Markets	TC 11: Auctions	TD 11: Learning in Economics		FC 11: Supply Chain Coordination
13 Software for OR 2605		WC 13: What's new in Solvers	WE 13: Optimization and AI	TA 13: Solver Interfaces	TC 13: Modeling	TD 13: Nonlinear Optimization	FA 13: OR Case Studies	FC 13: Algorithmic Advances

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Nordgebäude								
21, 22, 23 Mobility, Transport and Traffic **21** ZG 1070	WB 21: Airport and Airline Applications 1	WC 21: Airport and Airline Applications 2	WE 21: Airport and Airline Applications 3	TA 21: Railway Applications 1	TC 21: Railway Applications 2	TD 21: Railway Applications 3	FA 21: Transportation Network Design	FC 21: Maritime and Waterway Applications
22 ZG 1080	WB 22: Mobility Concepts	WC 22: Mobility and Electric Vehicles	WE 22: Emerging Trends in Mobility	TA 22: Urban Transportation and Traffic	TC 22: Last Mile Transportation 1	TD 22: Last Mile Transportation 2	FA 22: Bus Transportation	FC 22: Road Pricing and Congestion
23 ZG 1090	WB 23: Public Transportation	WC 23: Scheduling in Transportation 1	WE 23: Scheduling in Transportation 2	TA 23: Dial a Ride Problems	TC 23: Drone Transportation	TD 23: Ride Hailing and On Demand Transportation	FA 23: Innovative Applications in Transportation	FC 23: Traveling Salesman Problems

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Wirtschafts-wissenschaften								
08 Continuous and Global Optimization Z538	WB 08: Quadratic and Semidefinite Optimization	WC 08: Mixed-Integer Nonlinear Programming for Gas Networks	WE 08: Regularity in Continuous Optimization	TA 08: Optimal Control Applications	TC 08: Optimal Control Applications II	TD 08: Bilevel Optimization	FA 08: Novel Approaches for MINLP	
06, 07 Discrete and Combinatorial Optimization **06** Z534	WB 06: Packing Problems	WC 06: Vehicle Routing	WE 06: Facility Layout, Betweenness, and Quadratic Linear Ordering	TA 06: Applications of Combinatorial Optimization 1	TC 06: Applications of Combinatorial Optimization 2	TD 06: Quantum Computing	FA 06: Partitioning Problems	FC 06: Routing
07 Z536	WB 07: Column Generation	WC 07: Mixed Integer Programming	WE 07: Non-linear Multi-(level or criteria) Discrete Optimization	TA 07: Theory of Combinatorial Optimization 1	TC 07: Theory of Combinatorial Optimization 2		FA 07: Graphs and Steiner Trees	
09 Pricing and Revenue Management Z532	WB 09: Shared Mobility Pricing	WC 09: Competition in Pricing	WE 09: Pricing Applications	TA 09: Assortment Planning	TC 09: Network Revenue Management	TD 09: Revenue Management for Deliveries and Routing Problems	FA 09: E-Grocery Management	FC 09: Pricing

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15, 16, 17 SCM, Production, and Scheduling **15** 0534	WB 15: Forecasting Demand in Supply Chains	WC 15: Resilient Supply Chains	WE 15: Retail Supply Chains	TA 15: Logistics Platforms	TC 15: Green Supply Chains	TD 15: Reverse and Food Supply Chains	FA 15: Supply Planning	
16 0540	WB 16: Scheduling in Automotive Production	WC 16: Strategic Production Planning in Automotive Supply Chains	WE 16: Flow Shop Production	TA 16: Manufacturing Planning for Modular Products	TC 16: Material Handling / Warehousing	TD 16: Picking in Warehouses	FA 16: Production Challenges	FC 16: Continuous and Pharmaceutical Production
17 0544	WB 17: Machine Learning in Scheduling	WC 17: Project Scheduling	WE 17: Project Scheduling Applications	TA 17: Workforce Planning	TC 17: Transport Scheduling under Limited Battery Capacity	TD 17: Online and Disjunctive Scheduling	FA 17: Job Shop Scheduling	FC 17: Transportation Scheduling in Supply Chains
10 Service Operations and Healthcare 0514	WB 10: Health Care Logistics	WC 10: Integrated Planning in Health Care	WE 10: Retail and Staffing	TA 10: Medical Decision Support	TC 10: Patient Transportation	TD 10: Workforce Scheduling	FA 10: Logistics and Rescue in Healthcare	FC 10: Patient Operations

	WB	WC	WE	TA	TC	TD	FA	FC
	Wednesday 11.00 – 12.00	Wednesday 13.00 – 14.30	Wednesday 16.30 – 18.00	Thursday 8.30 – 10.00	Thursday 11.30 – 13.00	Thursday 14.00 – 15.30	Friday 8.30 – 9.30	Friday 10.45 – 12.15
Wienandsbau								
04, 05 Optimization under Uncertainty **04** 2999	WB 04: Applications of Dynamic and Stochastic Optimization	WC 04: Stochastic and Robust Optimization: Theory and Applications	WE 04: Logistics and Transportation under Uncertainty	TA 04: Applications of Stochastic Optimization		TD 04: Location and Supply Chain Management under Uncertainty	FA 04: New Approaches to Optimization under Uncertainty 2	FC 04: New Developments in Optimization under Uncertainty
05 3999		WC 05: Methods for Robust and Stochastic Optimization 1	WE 05: Methods for Robust and Stochastic Optimization 2	TA 05: New Approaches to Optimization under Uncertainty				

Presentations

WA 01: Opening Session & Plenary Romero Morales

Time: Wednesday, 04/Sept/2024: 8:30am - 10:30am · *Location:* Audimax
Session Chair: Rainer Kolisch

Fairness and Transparency in AI: An OR Perspective

Dolores Romero Morales
Copenhagen Business School, Denmark; drm.eco@cbs.dk

The use of Artificial Intelligence and Machine Learning algorithms to aid Decision Making is very widespread. State-of-the-art algorithms such as Random Forest, XGBoost and Deep Learning are built in the pursuit of high accuracy. However, it is not easy to explain how these powerful algorithms arrive at their predictions. There are well documented examples in which this lack of algorithmic transparency has had a negative impact on citizens' lives. The opaqueness may hide unfair outcomes for risk groups, such as the lack of equal opportunities in access to social services, lending decisions or parole applications. Therefore, there is an urgent need to strike a balance between three goals, namely, accuracy, explainability and fairness. In this presentation, and with an Operations Research perspective, we will navigate through some novel Machine Learning models that embed explainability and fairness in their training.

WB 02: Learning for Optimization 1

Time: Wednesday, 04/Sept/2024: 11:00am - 12:00pm · *Location:* Theresianum 0602
Session Chair: Tobias Klein

Learning to Filter State-Expanded Networks for Two-Stage Stochastic Programming

Michael Römer

Bielefeld University, Germany; michael.roemer@uni-bielefeld.de

Mixed-integer linear programming models relying on state-expanded networks have been shown to yield be highly efficient formulations for certain problem classes such as personnel scheduling. In recent works, we demonstrated that Machine Learning can be used to heuristically reduce the size of large-scale state-expanded networks, resulting in significant reductions in model size and solution time while exhibiting a negligible impact on solution quality. In this talk, we propose to apply this approach in the context of optimization under uncertainty, namely in a two-stage stochastic programming approach for shift scheduling with stochastic demands. In particular, we show how to use information from solving the LP relaxations of deterministic instances for multiple demand scenarios to train a Machine Learning model which is then used to filter the state-expanded networks to be used in the stochastic programming model. In a set of computational experiments, we show that the resulting drastic reduction of the model size can either be used to solving given stochastic programming models much faster or to solve models with a much larger number of scenarios compared to models relying on the non-filtered state-expanded networks.

Graph Convolutional Neural Network Assisted Monte Carlo Tree Search for the Capacitated Vehicle Routing Problem with Time Windows

Jorin Dornemann[1], Tobias Klein[2], Kathrin Fischer[2], Anusch Taraz[1]

[1]Institute of Mathematics, Hamburg University of Technology, Germany; [2]Institute for Operations Research and Information Systems, Hamburg University of Technology, Germany; tobias.klein@tuhh.de

The Capacitated Vehicle Routing Problem with Time Windows (CVRPTW) is a well-known combinatorial optimization problem that extends the classical Vehicle Routing Problem to account for additional real-world constraints such as truck capacity and customer time windows. Recent studies have explored the use of deep graph convolutional networks (GCNs) to predict the arcs that are part of the optimal tour for the Travelling Salesman Problem and related routing problems. We propose a novel context complemented graph convolutional network (CCGCN) which is integrated into a Monte Carlo Tree Search (MCTS) to solve the CVRPTW sequentially. The deep convolutional part of the proposed neural network builds efficient CVRPTW graph representations, whereas the context part processes information of partially built tours to output probabilities on which vertex to add next to the tour, which are used during the expansion of the search tree. For simulating final solution values within the Monte Carlo search tree, we conducted experiments using two different heuristics: LKH and a beam search. By leveraging the probabilities provided by our CCGCN and employing a variation of Upper Confidence Bound applied to trees, we effectively manage the tradeoff between exploration and exploitation, thus reducing the optimality gap compared to solutions generated solely by LKH. Evaluations of the proposed heuristic are performed on benchmark instances of the CVRPTW with up to 100 customers; these show promising results.

WB 03: Applications of Analytics

Time: Wednesday, 04/Sept/2024: 11:00am - 12:00pm · *Location:* Theresianum 0606
Session Chair: Songul Cinaroglu

Realizing adaptive process chains - a practical example from the automotive sector

Elisabeth Jung, Michael Mayer, Magdalena Schober

OptWare GmbH, Germany; michael.mayer@optware.de

In the dynamic landscape of industrial manufacturing, adaptability is key to efficiency and precision, especially in the automotive sector. As part of the research project AdaProQ we focus on the implementation of adaptive process chain optimization, combining machine learning (ML) and mathematical optimization to enhance manufacturing processes. At the core of our approach is the development of a prescriptive model capable of adaptively controlling the manufacturing process based on real-time data and predictive analytics.

We introduce the theoretical foundations of adaptive process chain optimization, including key definitions such as process chain, sensor variables, actuating variables, and target variables. Our objective is to train an ML model that serves as the basis for the optimization model, subsequently applying this model for real-time production optimization.

The aim of AdaProQ is the transfer from theory into practice. We demonstrate our approach on a metal forming process at a manufacturing company in the automotive sector. In detail, this encompassed understanding the process, categorizing variables, data preparation and analysis, and targeted data collection during a test day. This enabled the training of ML models and development of an optimization model, validated through a demonstrator.

Concluding, we discuss the success factors, challenges, and future perspectives of our project. Our findings underline the significant potential of adaptive process chain optimization in enhancing automotive manufacturing efficiency and quality, offering insights for ongoing research and development in the field.

Poverty analysis to identify household heterogeneity via deep clustering and Bayesian modeling of income and health expenditure using the GB2: blending machine learning analytics with uncertainty quantification techniques

Songul Cinaroglu[1], Sebastian Krumscheid[2]

[1]Hacettepe University, FEAS, Department of Health Care Management, Ankara, Turkiye; [2]Karlsruhe Institute of Technology, Scientific Computing Center (SCC), Karlsruhe, Germany; songulcinaroglu@gmail.com

The effectiveness of multidimensional poverty analysis can be enhanced through a more cohesive integration of machine learning (ML) techniques and poverty exploration combined with Bayesian estimates. This study focused on multidimensional poverty analytics, employing a blended strategy encompassing heuristic data generation, manifold learning, deep clustering, and Bayesian uncertainty quantification techniques. Specifically, the study utilized data collected from Turkish household budget surveys conducted between 2015 and 2019. To address the class imbalance between poverty classes, the synthetic minority oversampling technique (ubSMOTE) was employed to generate synthetic datasets. All analyses were conducted on the original highly imbalanced and synthetic datasets for comparison. Effective dimension reduction and clustering techniques, namely uniform manifold approximation and projection and Gaussian Mixture Model clustering, were employed to reduce data dimensionality and establish homogeneous household groups. Statistically significant differences ($p < 0.001$) were observed in the poverty prediction performances of ML models between the original highly imbalanced and synthetic datasets, with random forest outperforming other classifiers (CA: 98.66%). Decision tree and boosting integrated ML models outperformed popular ML algorithms in poverty prediction. In our study key predictors of poverty include income, out-of-pocket health expenditure (OOPHE), and household welfare clusters. Bayesian estimates of poverty using the Gini index with the GB2 distribution revealed that the level of inequality was higher for OOPHE compared to income across all study years. The results of this study contribute to a comprehensive understanding of poverty analysis, a crucial element in governing poverty analytics and achieving sustainable development goals.

WB 04: Applications of Dynamic and Stochastic Optimization

Time: Wednesday, 04/Sept/2024: 11:00am - 12:00pm · *Location:* Wienandsbau 2999
Session Chair: Philipp Melchiors

A Sim-Learnheuristic Algorithm For Solving a Stochastic and Dynamic Capacitated Dispersion Problem

Elnaz Ghorbani[1,2], Juan F. Gomez[2], Angel A. Juan[2], Javier Panadero[3]

[1]Department of Computer Science, Universitat Oberta de Catalunya, 08018 Barcelona, Spain; [2]Research Center on Production Management and Engineering, Universitat Politecnica de Valencia, 03801 Alcoy, Spain; [3]Department of Computer Architecture & Operating Systems, Universitat Autonoma de Barcelona, 08193 Bellaterra, Spain; eghorbanioskalaei@uoc.edu

A fundamental assumption in addressing real-world problems is acknowledging the presence of uncertainty and dynamism. Dismissing these factors can lead to the formulation of an optimal solution for an entirely different problem. This paper presents a novel variant of the capacitated dispersion problem (CDP) referred to as the stochastic and dynamic CDP. The main objective of this problem is to strategically position facilities to achieve maximum dispersion while meeting the capacity demand constraint. The proposed approach combines stochastic and dynamic elements, introducing a new paradigm to address the problem. This innovation allows us to consider more realistic and flexible environments. To solve this challenging problem, a novel sim-learnheuristic algorithm is proposed. This algorithm combines a biased-randomized metaheuristic (optimization component) with a simulation component (to model the uncertainty) and a machine learning component (to model dynamic behavior). Based on an extended set of traditional benchmarks for the CDP, a series of computational experiments are carried out. The results demonstrate the effectiveness of the proposed sim-learnheuristic approach for solving the CDP under dynamic and stochastic scenarios. The adoption of this innovative methodology opens up avenues for future research in the field of operations research and optimization. Exploring extensions and adaptations of this approach to other related problem domains could yield valuable insights and contribute to the development of more robust decision support systems. In conclusion, the integration of stochastic and dynamic elements into traditional optimization problems like the CDP represents a promising direction for advancing the state-of-the-art in operations research.

Priority Rules for the Dynamic Stochastic Resource Constrained Multi-Project Scheduling Problem in the context of R&D-projects under fairly general conditions

Philipp Melchiors[1], Rainer Kolisch[2], John J. Kanet[3]

[1]Cosmo Consult Data & Analytics GmbH, Germany; [2]TUM School of Management, Technical University of Munich, Munich, Germany; [3]School of Business Administration, University of Dayton, Dayton, USA; philipp.melchiors@cosmoconsult.com

We consider a multi-project setting where projects arrive stochastically over time and activity durations are stochastic. Each activity of a project has to seize one unit of a resource in order to be processed. Resources have multiple capacity units. For each unit of a resource, a priority rule decides on the next activity processed once the unit becomes available. The objective is to minimize the average weighted tardiness of the projects. In a previous study we have studied the performance of well-known priority rules from multi-project and job shop scheduling. In this study we investigate the performance of these rules when assumptions such as probability distributions and project networks are generalized.

WB 06: Packing Problems

Time: Wednesday, 04/Sept/2024: 11:00am - 12:00pm · *Location:* Wirtschaftswissenschaften Z534
Session Chair: John Martinovic

Solving hard Steiner tree packing problems using decision-guided SAT

Stefan Hougardy, Jan Malte Schürks
University of Bonn, Germany; schuerks@dm.uni-bonn.de

Steiner tree packing problems under arbitrary constraints occur naturally in VLSI routing. Traditionally many of these problems are solved using rip-up and reroute algorithms which quickly yield solutions with good netlength, but often fail to obey all design rules. Straightforward SAT-based approaches can easily obey the design rules, but produce unusable results with regard to netlength. We present a new algorithm utilizing elements of both approaches. This algorithm quickly produces results with good netlength in practice, while providing a guarantee that the computed solution will obey all design rules.

We apply this algorithm in the context of transistor-level routing, which involves more complex design rules and higher packing densities than chip-level routing. We present results on a cell library for a commercial 2nm node.

An Introduction to the Overflowing Bin Packing Problem

John Martinovic, Nico Strasdat
Technische Universität Dresden, Germany; john.martinovic@tu-dresden.de

We consider a recently proposed one-dimensional packing problem, called the overflow bin packing problem (OBPP). In this scenario, we are given a set of items (of known sizes) and a set of bins (of known capacities). Roughly speaking, the task is to assign the items to the bins in such a way that the total load of every bin is as close as possible to its capacity. In this talk, we first separate the problem under consideration from related partitioning problems, thus justifying its status as an independent branch of research. Subsequently, we review an assignment model known from the literature and investigate its theoretical properties. As a main result, we give a closed-form term for the associated LP bound and specify its worst-case performance ratio. In the second part, we then present a novel flow-based approach and show its numerical benefits by means of extensive computational tests with different benchmark sets. In particular, the new ILP formulation succeeds in solving all the considered instances to proven optimality in short time.

WB 07: Column Generation

Time: Wednesday, 04/Sept/2024: 11:00am - 12:00pm · *Location:* Wirtschaftswissenschaften Z536
Session Chair: Marco Lübbecke

A Polyhedral Hierarchy from Dantzig-Wolfe Reformulations of Stable Set Problems

Adrian Gallus

RWTH Aachen, Germany; adrian.gallus@rwth-aachen.de

We study all possible Dantzig-Wolfe reformulations of stable set problems and how they relate to each other. In particular, we show that any two reformulations lead to identical polyhedra if and only if the corresponding decompositions contain the same odd induced cycles. Moreover, for instances on complete graphs, it is shown that any two reformulations are asymptotically almost surely different. One could thus expect to obtain a unique dual bound from each of the many polyhedra. In contrast, we observe only a few different dual bounds in our computational experiments. This agrees with earlier observations by Bastubbe, Lübbecke, and Witt, which remain largely unexplained.

A Row-and-Column Generation Approach to Min-Sum Job-Shop Scheduling

Marco Lübbecke[1], Sarah Roth[2]

[1]RWTH Aachen University, Germany; [2]Ford, Germany; marco.luebbecke@rwth-aachen.de

We report on an exact approach to min-sum job-shop scheduling which builds on and combines ingredients that have been around in the literature for some time. The first is the idea of using an extended formulation for the problem, in this case essentially a network flow model on a time-indexed graph. Secondly, such formulations can be decomposed (leading to Lagrangian or Dantzig-Wolfe based approaches), either with so-called job-level or machine-level subproblems, or both, leading to strong dual bounds. We use machine-level subproblems. Thirdly, working with time-indexed models directly is often computationally limited because of their sheer size, and the so-called row-and-column generation paradigm suits this well in order to dynamically generate the network. And this is it (well, with some branching, cutting, and primal heuristics), and it worked for us. For several instances (minimum weighted completion time objective) from the literature we can prove optimality for the first time, or improve the best known dual or the primal bounds, respectively. These computational results are almost ten years old, but we never reported on them. In the end we look at a practical application from scheduling in a health care environment, which we came across only recently.

WB 08: Quadratic and Semidefinite Optimization

Time: Wednesday, 04/Sept/2024: 11:00am - 12:00pm · *Location:* Wirtschaftswissenschaften Z538
Session Chair: Jan Krause

A low-rank high-precision solver for semidefinite programming

Daniel Brosch, Jan Schwiddessen, Angelika Wiegele
University of Klagenfurt, Austria; jan.schwiddessen@aau.at

Low-rank approaches for solving semidefinite programs have recently attracted a lot of attention. In this talk, we present a new solver for semidefinite programs that is capable of computing solutions with arbitrary precision. The idea is to employ the non-convex Burer-Monteiro reformulation to exploit low-rank structure of SDP solutions. We base our approach on a variant of the so-called Mixing Method for diagonally constrained SDPs. The latter implements a coordinate descent approach with respect to the rows/columns of the Burer-Monteiro factorization matrix.

We follow the original approach of Burer and Monteiro and employ an augmented Lagrangian approach to solve the non-convex reformulation. However, instead of minimizing the augmented Lagrangian with respect to the whole factorization matrix, we borrow the idea of minimizing with respect to a single row/column at a time from the Mixing Method, leading to an ADMM-style method. We present promising results on various classes of semidefinite programs, showing that the approach has practical good convergence properties if it is warm-stared from a solution close to the optimum. Our Julia implementation can use arbitrary precision arithmetic and allows the user to solve semidefinite programs to any user-specified precision.

The Bipartite Quadric Polytope with Partitioned Subtotal Constraints and its Application to Pooling Problems

Jan Krause[1], Robert Burlacu[1], Christof Kümpel[2], Oskar Schneider[3]
[1]University of Technology Nuremberg, Germany; [2]KPMG, Germany; [3]Horváth, Germany; jan.krause@utn.de

The well-known boolean quadric polytope was introduced by Manfred Padberg in 1989. We study a similar, but more structured version of the latter which we call the bipartite quadric polytope with partitioned subtotal constraints. Here we assume a bipartition on the variables and besides the bilinear product equations, we consider additional linear constraints on one of the variable sets. Elementary polyhedral properties are discussed, including vertex characteristics and valid resp. facet-defining inequalities. In addition to the adaption of the known RLT-inequalities, we find a new class that we call subset-m inequalities. Furthermore, we investigate a certain variant of the pooling problem that contains the mentioned polytope as a substructure and demonstrate the potential of found cutting planes in this application.

WB 09: Shared Mobility Pricing

Time: Wednesday, 04/Sept/2024: 11:00am - 12:00pm · *Location:* Wirtschaftswissenschaften Z532
Session Chair: Matthias Soppert

Sustainability-oriented Dynamic Pricing for Shared Mobility-on-Demand Systems

Fabian Anzenhofer[1], David Fleckenstein[1], Robert Klein[1], Claudius Steinhardt[2]

[1]University of Augsburg, Germany; [2]University of the Bundeswehr Munich, Germany; david.fleckenstein@wiwi.uni-augsburg.de

Shared mobility-on-demand (SMOD) systems are expected to make public transport more sustainable, especially in rural areas. From the social perspective, this means that an SMOD system should contribute to providing area-wide, reliable, and non-discriminatory access to mobility. In ecological terms, the main aim is to decrease emissions per passenger kilometer and to prevent that the SMOD service cannibalizes scheduled public transport services. Finally, economic efficiency must also be considered to limit the subsidy requirements while avoiding that the provider increases prices purely for capitalizing on the consumer surplus. Since providers typically offer customers multiple fulfillment options, i.e., rides with alternative pick-up times, dynamic pricing can be applied to actively steer demand, and thereby, improve the system's sustainability. In this talk, we discuss how the resulting integrated demand management and vehicle routing problem can be modeled. Thereby, we consider sustainability-based objectives in addition to the usual profit maximization. We focus particularly on the dynamic pricing sub-problem, which can be cast as a multi-objective, constrained assortment optimization problem. Finally, we present a decomposition-based solution concept, which we evaluate based on real-world data from a rural SMOD provider.

Customer-Centric Dynamic Pricing for Free-Floating Vehicle Sharing Systems

Matthias Soppert[1], Claudius Steihardt[1], Christian Müller[2], Jochen Gönsch[2]

[1]University of the Bundeswehr Munich; [2]University of Duisburg-Essen; matthias.soppert@unibw.de

Free-floating vehicle sharing systems such as car sharing systems offer customers the flexibility to pick up and drop off vehicles at any location within the business area. However, this flexibility comes with the drawback that vehicles tend to accumulate at locations with low demand. To counter these imbalances, pricing has proven to be an effective and cost-efficient means. The fact that modern systems rely on mobile applications for their communication with customers, combined with the fact that providers know the exact location of each vehicle in real-time, offers new opportunities for pricing. We develop a profit-maximizing dynamic pricing approach which is customer-centric, meaning that, whenever a customer opens the mobile application, the price optimization incorporates the customer's location as well as the customer's choice behavior. In particular, it considers the effects of prices and walking distances to available vehicles on the customer's rental decision. Further, the approach anticipates future vehicle locations, rentals, and profits. More specifically, we propose an approximate dynamic programming-based solution approach with nonparametric value function approximation. It allows direct application in practice, because historical data can readily be used and key parameters can be precomputed such that the online pricing problem becomes tractable.

WB 10: Health Care Logistics

Time: Wednesday, 04/Sept/2024: 11:00am - 12:00pm · *Location:* Wirtschaftswissenschaften 0514
Session Chair: Markus Förstel

Social Care Logistics: challenges and opportunities

Maria Isabel Gomes[1], Helena Ramalhinho[2]

[1]NOVA Faculty of Sceince and Technology, Portugal; [2]Universitat Pompeu Fabra, Spain; mirg@fct.unl.pt

The United Nations Sustainable Development Goals (SDGs) aim to address global challenges that affect all nations. While the SDGs are commonly perceived as primarily for developing countries, they set ambitious goals that are relevant to all nations. Developed countries are also grappling, to varying degrees, with social issues such as poverty and isolation. Delivering services in this context presents unique challenges, as the service recipients are people in vulnerable conditions. Optimizing logistics services through OR models can significantly improve decision-making in what we have been calling Social Care Logistics.

Social Care Logistics refers to all logistical activities that facilitate service delivery to individuals who require social support in their everyday lives. The talk focuses on two crucial challenges encountered by developed nations: an aging population and food insecurity. In the context of an aging population we will focus on the home social care problem, where we explore how traditional routing and scheduling models can be adapted to efficiently plan caregiver routes while taking into account the unique nuances that differentiate this context from the conventional vehicle routing problem. Concerning food insecurity, we will analyze the differences between traditional supply chains and those of food banks, highlighting the unique logistical challenges involved in distributing food to vulnerable populations.

Impact of Vohenstrauß Hospital Closure on Patient Distribution at Weiden Hospital

Markus Förstel[1], Stefan Förstel[1,2], Eva Rothgang[1]

[1]Ostbayerische Technische Hochschule Amberg-Weiden, Germany; [2]Friedrich Alexander Universität Erlangen, Germany; m.foerstel@oth-aw.de

Germany has a well-equipped healthcare system that spends the highest percentage of its GDP on healthcare in Europe and has the second highest number of hospital beds per 1,000 inhabitants at 7.8, well above the EU average of 4.8. At the same time, the country has a lower avoidable mortality rate and a life expectancy comparable to the EU average, according to reports by the OECD/European Observatory on Health Systems and Policies (2023). These statistics suggest a solid infrastructure, but also highlight areas where healthcare outcomes can be improved. This study examines the effects of the closure of Vohenstrauß Hospital in July 2020, with a total of 40 hospital beds, on the flow of patients to Weiden Hospital, approximately 14.5 km away, with a total of 649 hospital beds. By analyzing geographical data on the origin of patients and hospital visits over the last thirty years, we found that the closure of Vohenstrauß hospital had only a minimal impact on the flow of patients to Weiden. Our results suggest that the regional healthcare network has adapted effectively, with patients likely to have moved to outpatient providers such as general practitioners. Despite the closure, patient volumes remained the same before and after. This suggests that the quality of healthcare is more important to outcomes than the number of beds or hospitals.

WB 11: Behavioral Decisions 1

Time: Wednesday, 04/Sept/2024: 11:00am - 12:00pm · *Location:* Theresianum 2609
Session Chair: Christian Jost

Points and Cards - A behavioral view of the decision-making under equivalent inventory policies

Alexander Daniels, Guido Voigt

University of Hamburg, Germany; Alexander.Daniels@uni-hamburg.de

Many inventory decisions are made by humans influenced by behavioral effects. These effects can lead to losses through stockouts or excessive inventory. This work tries to shed light on the behavioral impacts on decision-making in frequently used order policies. The two investigated inventory policies are the (r, n*Q, t)-policy and the periodic Kanban.

These inventory policies are very similar and become equivalent if certain criteria are met. In this work, we assume stochastically normal distributed demand, lost sales, and periodic review cycles. A between-subject laboratory experiment was conducted. The findings show significant differences in decision-making between the two policies. Decision-making under both policies seems to be influenced by anchoring on “prominent” or round numbers in their respective decisions.

Can Working Iteratively Drive Innovation?

Evgeny Kagan[1], Tobias Lieberum[2], Sebastian Schiffels[3], Christian Jost[4]

[1]Johns Hopkins University; [2]CyberDesk GmbH; [3]University of Augsburg; [4]Technical University of Munich; christian.jost@tum.de

Motivated by the widespread adoption of project management techniques like Agile and Scrum, we compare the effects of iterative versus sequential workflow on innovative behavior and performance. In our laboratory experiments, we find that in an open-ended creative design challenge, iterative task completion outperforms sequential task completion. In a second experiment, we show that the performance advantage of the iterative workflow persists in settings that do not involve creative idea generation. This result can be explained by the frequent task-switching in the iterative workflow, which promotes a broader exploration of alternative solutions. Indeed, a third experiment reveals that the sequential workflow results in a more myopic idea refinement, often trapping the innovation process in local optima. Taken together, our results suggest that the iterative workflow improves performance across multiple, structurally distinct innovation settings. Moreover, we identify the following three boundary conditions for our result. First, working iteratively helps to achieve quick performance gains, but the performance advantage diminishes over time. Second, iterative workflow mainly benefits low performers and has minimal effect on top performers. Third, the iterative workflow can be detrimental in projects with strong path dependencies.

WB 15: Forecasting Demand in Supply Chains

Time: Wednesday, 04/Sept/2024: 11:00am - 12:00pm · *Location:* Wirtschaftswissenschaften 0534
Session Chair: Carsten Jordan

Leveraging Polytope Volume Computation and Modern Benchmarking for Demand Prediction and Product Evaluation

Mohsen Afsharian[1], Peter Bogetoft[2]

[1]Leibniz-FH, University of Applied Sciences, Germany; [2]Copenhagen Business School, Denmark; mohsen.afsharian@leibniz-fh.de

This paper addresses the challenge of evaluating existing product alternatives and predicting demand for new entries. We propose two innovative solution approaches. The first is associated with polytope volume computation designed to predict demand shifts resulting from the introduction of new products. We investigate the interrelated challenges, including computational intensity, scalability issues, sensitivity to data quality, and interpretability concerns. In response, we propose the second approach that leverages modern benchmarking. This approach provides a more user-friendly and transparent framework for assessing and predicting demands, complementing the complexity of polytope volume computation. To illustrate the applicability and effectiveness of our approaches, we provide an empirical illustration within the pharmaceutical industry, focusing on the competitive market for diabetes medications in Denmark. This study highlights the potential of our approaches in enhancing decision-making processes, thereby contributing to various aspects of planning within pharmaceutical supply chain management.

Supply Planning with Kinaxis RapidResponse

Carsten Jordan, Tobias Schulz

Kinaxis, United States of America; cjordan@kinaxis.com

We will cover how we incorporate optimization algorithms into the supply chain management system RapidResponse and which challenges arise in real world cases. One aspect is the combination of heuristics and linear optimization techniques to handle large scale, end-to-end supply planning instances. We conclude with a discussion of customer use cases and promising product enhancements.

WB 16: Scheduling in Automotive Production

Time: Wednesday, 04/Sept/2024: 11:00am - 12:00pm · *Location:* Wirtschaftswissenschaften 0540
Session Chair: Timur Alexander Wohlleber

Resource-constrained multi-project scheduling with project splitting: an application from automotive prototype manufacturing

Christian Weckenborg[1], Yossi Bukchin[2], Tevhide Altekin[3]
[1]Technische Universität Braunschweig, Germany; [2]Tel Aviv University, Israel; [3]Sabanci University, Turkey; c.weckenborg@aip-pl.tu-braunschweig.de

In the context of product development within the automotive industry, physical prototype vehicles with new functions and components need to be built for testing and validation. The assembly of prototype vehicles is carried out through a manual process without automated assembly activities, thus requiring highly skilled workers capable of manually assembling vehicles. It is conducted stationary on lifting platforms, where the vehicles are mounted during assembly. A master craftsperson is responsible for coordinating the assembly of the assigned orders. Therefore, they allocate the vehicles to lifting platforms, schedule their assembly activities, and allocate the workers to them. Since prototype parts often undergo last-minute changes, not all required components are usually available at the beginning of the assembly process. Therefore, the assembly may be started even when not all parts are available to avoid delays in subsequent testing. Typically, the vehicles remain on the lifting platforms from the start of their assembly until completion. However, the master craftsperson can optionally decide to remove a partially assembled vehicle from the platform and allocate this resource to assemble another vehicle.

We model this problem as a resource-constrained project scheduling problem with multiple (vehicle) projects (RCMPSP). We use optional activities to model the mounting and unmounting of vehicles onto lifting platforms, effectively splitting the projects. Notably, our approach is the first to integrate decisions on project splitting into RCMPSP approaches. Based on numerical experiments, the potential of project splitting is assessed.

A part-supply-oriented resequencing approach for automotive assembly

Timur Alexander Wohlleber, Martin Grunow
Technical University of Munich, Germany; timur.wohlleber@tum.de

Automotive manufacturers have improved supply chain efficiency by introducing lean part delivery methods like just-in-sequence. Approaches such as the pearl chain concept (or in-line vehicle sequencing) take this even further by outsourcing part sequencing to suppliers. To facilitate this, the sequence on the final assembly line is determined several days in advance. However, the necessity to adhere to already communicated order sequences poses challenges for production planners in case of unexpected supply shortages. Sequence changes are restricted by warehouse storage and handling capacities because all parts delivered in sequence must be rearranged. An interim solution is to assemble vehicles without the missing parts and install them later in a rework step. However, this mechanism is limited by the manufacturing capacity for rework and the space available for storing incomplete vehicles. This frequently implies that resequencing or rework are no longer feasible resulting in costly production shutdowns. We introduce a car resequencing approach in pearl chain-controlled factories. The core idea is to cut segments from the pearl chain based on their exposure to supply shortages while considering the delivery lot sizes in which parts are supplied. This rescheduling of segments instead of single vehicle orders helps reduce the effort for part rearrangement. Simultaneously, we maintain a high production capacity utilization through the controlled deployment of rework and by pulling vehicles without shortages forward. We show the viability of our concept on a dataset of real vehicle sequences, missing parts, and lot sizes for part supply.

WB 17: Machine Learning in Scheduling

Time: Wednesday, 04/Sept/2024: 11:00am - 12:00pm · *Location:* Wirtschaftswissenschaften 0544
Session Chair: Philipp Willms

A supervised machine learning approach for replenishment order decisions under transportation cost uncertainty

Pirmin Fontaine[1], Daniel Müllerklein[1], Janosch Ortmann[2]
[1]Catholic University of Eichstätt-Ingolstadt, Germany; [2]Université du Québec à Montréal, Canada; pirmin.fontaine@ku.de

Companies worldwide seek a balance between risks and cost-efficiency in their supply chains. Due to the increase in extreme weather events, global inland waterway transport disruptions gained growing attention as shipment carriers enforce contractual surcharges to account for capacity losses. To improve efficiency and resilience, one open question is, therefore, when and how much to transport from which of the multiple suppliers considering their lead time differences and account for the transportation cost uncertainty driven by the enforced surcharges.

We formulate this problem as a stochastic Inventory Routing Problem with Direct Deliveries and introducing a new Cost Focused Machine Learning (CFML) framework. Compared to existing approaches, we perform a hyperparameter tuning where the costs of applying the resulting transportation decisions are optimized instead of the prediction score of the individual decisions of the machine learning model.

We evaluate our CFML in a case study, based on a chemical company at the border of the river Rhine. Relevant features for our CFML include the inventory position, historical water level, their trends, and predictions. While traditional learning approaches result in inefficient policies, we show that our CFML can reduce costs by 18% compared to classical machine learning frameworks and more than 20% compared to a standard (s,Q)-reorder policy representing industry standard.

Accelerated scheduling heuristics for reinforcement learning approaches applied to the Westenberger-Kallrath problem

Philipp Willms[1,2], Marcus Brandenburg[1,2]
[1]University of Kassel, Germany; [2]Flensburg University of Applied Sciences, Germany; philipp.willms@uni-kassel.de

In the chemical process industry, production planning and scheduling (PPS) problems show a variety of characteristics which increases the complexity of corresponding modeling approaches and solution techniques. For recent years, the concept of reinforcement learning (RL) has been evaluated for its effectiveness to solve PPS problems for multiple case studies in discrete manufacturing. Our study delves into the utilization of RL to address the Westenberger-Kallrath (WK) problem which is a prominent benchmark for chemical production planning. The proposed solution approach decouples the lotsizing part from the scheduling activity via a custom MRP heuristic which creates chains of batches linked to customer orders. We train an RL agent to find the best sequence of scheduling those chains with the objective to minimize overall makespan. Building on our previous work, which used a custom forward scheduling heuristic with an internal inventory projection, we propose a new scheduling logic based on minimum waiting times between the multi-stage processes and their assigned resources. We provide a comprehensive performance comparison between two implementation approaches, evaluating criteria such as makespan, inventory and resource utilization. Apart from the effectiveness measures, a CPU time comparison proves the efficiency of our new method. Using the new logic in RL agent training, we detect further modeling challenges regarding reward function design, which provide future research perspectives on RL for PPS problems in chemical process industry.

WB 18: Heating Networks

Time: Wednesday, 04/Sept/2024: 11:00am - 12:00pm · *Location:* Theresianum 0601
Session Chair: Maik Günther

Long-term multi-objective optimization for integrated unit commitment and investment planning for district heating networks

Stephanie Riedmüller, Fabian Rivetta, Janina Zittel
Zuse Institute Berlin, Germany; riedmueller@zib.de

The need to decarbonize the energy system has led to an intensified focus on district heating networks in urban and suburban areas. Therefore, exploring transformation pathways with reasonable trade-offs between economic viability and environmental goals became necessary.

We introduce a novel network-flow-based model class integrating unit commitment and long-term investment planning for district heating networks incorporating multi-energy markets. While the integration of unit commitment and investment planning has been studied for electrical and multi-energy systems, suitability for the application of long-term portfolio planning of a single district heating provider on an urban scale has yet to be met. Based on mixed integer linear programming, the model bridges the gap between overly detailed industrial modeling tools not designed for computational efficiency at scale and rather abstract academic models.

The formulation is tested on Berlin's district heating network, including potential investments with a 25-year depreciation period. Hence, the challenge lies in the large number of variables and constraints and the coupling of time steps through investment decisions.

A case study explores different solutions on the Pareto front defined by optimal trade-offs between minimizing costs and CO2 emissions through a lexicographic optimization approach, i.e., optimal costs are relaxed incrementally before prioritizing CO2 emission reduction.

The resulting solution catalog can provide decision-makers valuable insights into feasible transformation pathways, highlighting distinctions between robust and target-dependent investments. This study's findings further emphasize the significance of integrating unit commitment into investment planning to provide a nuanced understanding of possible ways to decarbonize district heating.

Costs for transition of the heat sector in a large city: simulation of scenarios with a digital twin

Maik Günther[1,2]
[1]IU International University of Applied Sciences; [2]Stadtwerke München GmbH; maik.guenther@iu.org

A functioning transition of the heat sector is a prerequisite for the success of the energy transition as a whole. Against this backdrop, Germany has set itself the target of using only renewable energies and unavoidable waste heat in the heat sector by 2045 at the latest. For this purpose, among other measures, the Heat Planning Act was created, which regulates the development of municipal heat plans. The Stadtwerke München (SWM) have developed the 'Model Munich', a building-specific geographic information system containing data on heat demand, heating system, construction year etc., which is coupled with the multi-agent system Invert/EE-Lab. This enables the simulation of building-specific long-term scenarios regarding renovation rates and depths, as well as the selection of systems for space heating and hot water generation. The 'Model Munich' in combination with the multi-agent simulation model Invert/EE-Lab was used by the city of Munich to develop a municipal heat plan. The simulations of long-term scenarios for the transition of the heat sector consider building-specific investment and operating costs. For example, this allows the quantification of the additional costs associated with higher renovation rates and depths needed to achieve the goals of the Heat Planning Act. Furthermore, analyses can be made regarding the effects of higher carbon prices or changes in subsidies.

WB 19: Multi-criteria Decision Making

Time: Wednesday, 04/Sept/2024: 11:00am - 12:00pm · *Location:* Theresianum 1601
Session Chair: Dorota Górecka

Multicriteria Adjustable Regret Robustness for Building Energy Supply Design

Elisabeth Halser, Elisabeth Finhold, Neele Leithäuser, Tobias Seidel, Karl-Heinz Küfer
Fraunhofer ITWM, Germany; elisabeth.halser@itwm.fraunhofer.de

Optimizing a building's energy supply design is an inherently multicriteria task, where not only monetary but also, for example, environmental objectives shall be taken into account. Moreover, when deciding which storages and heating and cooling units shall be purchased (here-and-now-decisions), there is also uncertainty about future developments of prices for energy, e.g. electricity and gas, that later can be accounted for by operating the units accordingly (wait-and-see-decisions), once the uncertainty revealed itself. This kind of problem is well known as an adjustable robust optimization problem. The combination of adjustable robustness and multicriteria optimization is only studied to limited extent in mathematics yet. The resulting problem can be solved using a column and constraint generation algorithm in combination with an epsilon-constraint approach.

We model the problem as a multicriteria adjustable robust problem, where we simultaneously minimize worst-case cost regret and carbon emissions. By cost regret, we mean the difference between the cost with the selected devices and the cost with the price scenario-specific optimal devices. We take into account future price uncertainties and consider the results in the light of information gap decision theory to find a trade-off between security against price fluctuations and over-conservatism. We present the model, a solution strategy and computational limits.

Enhancing Spatial Analysis through Reference Multi-Criteria Methods: A Study Evaluating EU Countries in terms of Sustainable Cities and Communities

Dorota Górecka[1], Ewa Roszkowska[2]
[1]Nicolaus Copernicus University in Toruń, Poland; [2]Bialystok University of Technology, Poland; dgorecka@umk.pl

Multidimensional regional socio-economic analyses should take into account the complexity and spatial diversity of the European Union (EU). Using reference multi-criteria methods, this paper proposes a comprehensive framework to facilitate spatial analyses. The methodology is based on two modified multi-criteria techniques, namely TOPSIS and BIPOLAR, which include reference points for evaluation and rank-ordering objects. In TOPSIS objects are ordered directly concerning distances from the ideal and the anti-ideal points, whereas in BIPOLAR they are compared indirectly utilising two sets of reference objects: desirable ("good") and undesirable ("bad"). Furthermore, the distinction between internal and external reference points is examined. The motivation behind this study lies in monitoring progress towards achieving Sustainable Development Goals (SDGs) in different areas while considering objectives set out in the Agenda 2030 - a complex plan of transformation for people, planet, peace, and prosperity adopted by United Nations Member States and focused on realizing 17 SDGs and 169 targets integrated into the economic, social, and environmental dimensions. To prove the usability of the proposed framework, we applied it to measure the spatial diversity of EU countries in terms of implementing SDG 11: Sustainable Cities and Communities. The analysis is conducted for the years 2015 and 2019 and is based on eight EU sustainable development indicators. The findings are showcased as rankings and depicted via maps for identifying analogous regions in the EU. The research indicates varying levels of achievement in meeting the SDG 11 objective among EU countries, with northern countries performing significantly better than southern ones.

WB 21: Airport and Airline Applications 1

Time: Wednesday, 04/Sept/2024: 11:00am - 12:00pm · *Location:* Nordgebäude ZG 1070
Session Chair: Katrin Heßler

Enhancing airport operations by integrating optimisation of terminal arrival route, runway assignment, and aircraft trajectories

Luis Cadarso[1], Raúl de Celis[1], Javier Faulin[2]

[1]Universidad Rey Juan Carlos, Spain; [2]Public University of Navarre, Spain; luis.cadarso@urjc.es

Managing incoming air traffic at airports presents a challenge due to the variety of air routes and limited runway capacity. This issue is particularly pronounced in terminal arrival routes, where careful coordination is crucial to avoid congestion. This study introduces an optimization model that addresses approach and landing operations, as well as terminal arrival routes. The model determines runway assignments, terminal arrival route selection, and aircraft trajectories, resulting in a complex optimization problem. To solve this, a Benders decomposition approach is proposed. The master model handles runway assignment and terminal arrival route selection using binary variables, while the submodel focuses on trajectory calculation, optimizing fuel consumption and minimizing delays with continuous variables.

OR in practice: Gateway Assignment Problem

Katrin Heßler, Lukas Wienkamp

Schenker AG, Germany; katrin.hessler@dbschenker.com

The Gateway Assignment Problem can be specified as follows: Given a set of shipments and a set of flights departing from different gateways, the task is to assign each shipment to a flight such that the total cost is minimized. The loading of flights is constrained by volume and weight capacities. What makes the problem interesting is a complicated cost function that not only considers transport costs from customers to the gateways, but also balances weight and volume utilization of the flights. In addition to presenting the cost function and a MIP model, the talk focuses on practical challenges, such as data issues and vague problem definitions, and how these were solved.

WB 22: Mobility Concepts

Time: Wednesday, 04/Sept/2024: 11:00am - 12:00pm · *Location:* Nordgebäude ZG 1080
Session Chair: Carlo Filippi

How do incentives impact the intention to use mobility as a service platforms? A choice-based conjoint analysis.

Antonia Klopfer[1], Gina Dohmen[2], Ruth Noppeney[3], Maren Paegert[4], Grit Walther[1]

[1]Chair of Operations Management at RWTH Aachen University, Germany; [2]Chair of Economic Geography at RWTH Aachen University; [3]Institute of Psychology, RWTH Aachen University; [4]Chair of Management Accounting, RWTH Aachen University; antonia.klopfer@om.rwth-aachen.de

Mobility as a Service (MaaS) promises the seamless and customized integration of the mobility services in a certain region into one digital platform, via which users can plan, book, and pay their trips. Although prior research indicates that MaaS can decrease greenhouse gas emissions and improve inclusiveness of the transport system, the user numbers remain low. The deployment of incentives can influence the mobility decisions of travelers and might encourage the adoption of MaaS platforms, if the incentives match the preferences of the potential users.

Against this background, we present the results of a stated-preference choice experiment, in which participants choose between MaaS platforms that vary regarding the included incentives. We weigh different economic, social, and ecological incentives against each other and generate insights about their attractiveness for potential users. The choice experiment shows a high importance of both ecological and economic incentives, while revealing a relatively lower importance of social attributes.

Our study contributes to the understanding of incentives for MaaS usage and gives impulses for the research on MaaS platform and bundle optimization. The results further serve as insights for policy-makers and practitioners with the aim of increasing the user numbers of MaaS systems and improving the sustainability of the transportation sector.

On the value of modular buses optimization

Carlo Filippi, Gianfranco Guastaroba, Lorenzo Peirano, M. Grazia Speranza

University of Brescia, Italy; carlo.filippi@unibs.it

Modular bus systems recently attracted attention due to their potential ability increase the flexibility and efficiency in transit networks scheduling. In this work, we focus on the potential advantages of modular buses with respect to fixed-capacity buses.

We develop a static optimization model to minimize the total number of modules flowing in a given network of bus lines. The model assumes that for a set of origin-destination pairs located at the stops of the bus network, a rate of transport demand is given and must be satisfied. Buses are formed by one or more connected identical modules. Modules can be attached/detached at the endpoints of a line and at intersections of lines. Empty modules can be transferred among different endpoints and intersections if needed. The model establishes the rate of departure of modules from each endpoint and intersection along each line and the rate of transfer of empty modules among endpoints and intersections that allow to satisfy the demand of transport using a minimum number of modules. By analyzing two extreme cases, we bound the relative value of module sharing among lines and the relative value of empty module rebalancing.

Computational experiments on instances derived from real-world transportation networks show the validity of the model and the saving in total transport capacity that can be obtained from a modular system with respect to a fixed-capacity system.

WB 23: Public Transportation

Time: Wednesday, 04/Sept/2024: 11:00am - 12:00pm · *Location:* Nordgebäude ZG 1090
Session Chair: Eric Ralf Kempkens

Analyzing Public Transport Accessibility: Incorporating Last-Mile Connectivity in a Weighted Graph Model

Lukas Spengler, Marc Gennat
Hochschule Niederrhein University of Applied Sciences, Germany; lukas.spengler@hs-niederrhein.de

The issue of the last mile in public transportation is crucial to its attractiveness and utilization, and thus represents one of the most significant challenges of the mobility transition in rural and urban areas. This contribution introduces a mathematical model represented as a directed and weighted graph to simulate public transit networks. The model is enhanced by incorporating edges that represent the last mile connections between transit stops and final destinations, addressing a critical gap in accessibility. These edges are assigned weights that vary based on the travel resistance, as evaluated using the established methodology for the standardized evaluation of transport infrastructure investments.

The methodology specifies a modal split proportion for public transit on a given route and computing the maximum allowable travel resistance as the objective function under specified constraints. This framework addresses the fundamental question of how the travel resistance of the last mile should be in order to achieve a desired modal shift towards public transit. The model can also be employed to investigate the acceleration of routes by omitting stops, which increases the last-mile problem for some customers, but reduces the travel time of the route. Using this framework, it is possible to estimate which public transport services, such as bike and scooter sharing or automated ridepooling, are required, which close certain gaps in comprehensive public transport coverage. By integrating last-mile connectivity, this model offers insights into the design of public transportation systems that promote higher usage while considering constraints of urban environments.

Computational Analysis of Potential Time Savings to Increase Mean Velocity of Public Transport

Eric Kempkens, Lukas Spengler, Marc Gennat
Hochschule Niederrhein University of Applied Sciences, Germany; eric.kempkens@stud.hn.de

Public transportation systems are a sustainable alternative to driving for commuters. In order to make these systems more attractive, local authorities need to prioritize the minimization of commute times in their planning process.

In this contribution, we present an approach to identify delays within the routes of public transport systems. This approach uses data from an Intermodal Transport Control System (ITCS) and OpenStreetMap to analyze the operation of public transport systems. Within each individual trip, avoidable and unavoidable obstacles like curves and traffic lights are identified, located, and classified as a basis for constructing the best-case scenario of the trip. This best-case scenario is constructed for public transport systems using acceleration and deceleration functions of the vehicle and takes into account unavoidable speed restrictions such as curves. If the best-case scenario offers time savings compared to the original trip, these savings are distributed source-specific among the identified causes via a dynamic weighting system. The computation results in the identification of the length, location and cause of avoidable delays within the transportation system operation. This algorithm can also be used to calculate the time savings from excluding stops in the route planning process.

This approach has been successfully used to identify the most time-consuming traffic light systems within the operation of the local tram system in the city of Krefeld, Germany. This research result of increasing the mean velocity is presented in this contribution.

WC 01: Hexaly Workshop

Time: Wednesday, 04/Sept/2024: 1:00pm - 2:30pm · *Location:* Audimax
Session Chair: Julien Darlay

Modeling and Solving Routing Problems with Hexaly Studio

Léa Blaise, Julien Darlay
Hexaly, France; jdarlay@hexaly.com

Hexaly Optimizer is a global mathematical solver combining exact and heuristic techniques. It offers an innovative set-based and nonlinear modeling formalism, that enables users to build simple and compact models for many types of combinatorial problems. These set-based modeling features also provide the solver with higher-level structures, that it can exploit by applying various techniques from the literature to obtain state-of-the-art results on routing, scheduling, and packing problems. In this workshop, we will see how to take advantage of this modeling formalism to model and solve routing problems. For that, we will invite participants to use Hexaly Studio, a specialized online code editor enhanced with dashboards and widgets to visualize the solutions.

WC 02: Learning for Optimization 2

Time: Wednesday, 04/Sept/2024: 1:00pm - 2:30pm · *Location:* Theresianum 0602
Session Chair: Maximiliane Rautenstrauß

Learning the Follower's Objective Function in Sequential Bilevel Games

Ioana Molan, Martin Schmidt, Johannes Thürauf

University Trier, Germany; molan@uni-trier.de

We consider bilevel optimization problems in which the leader has no or only partial knowledge about the objective function of the follower. The studied setting is a sequential one in which the bilevel game is played repeatedly. This allows the leader to learn the objective function of the follower over time. We focus on two methods: a multiplicative weight update (MWU) method and one based on the lower-level's KKT conditions that are used in the fashion of inverse optimization. The MWU method requires less assumptions but the convergence guarantee is also only on the objective function values, whereas the inverse KKT method requires stronger assumptions but actually allows to learn the objective function itself. The applicability of the proposed methods is shown using two case studies. First, we study a repeatedly played continuous knapsack interdiction problem and, second, a sequential bilevel pricing game in which the leader needs to learn the utility function of the follower.

Addressing Real-World Side Constraints in Combinatorial Optimization with Deep Reinforcement Learning

Nayeli Gast Zepeda, Kevin Tierney, André Hottung

Bielefeld University, Germany; nayeli.gast@uni-bielefeld.de

Deep Reinforcement Learning (DRL) methodologies have garnered increasing attention in addressing combinatorial optimization challenges, particularly in domains such as routing and scheduling. While recent approaches have demonstrated notable efficacy, especially in classic problems like the Traveling Salesman Problem (TSP) and Capacitated Vehicle Routing Problem (CVRP), they often operate within simplified problem settings, lacking real-world side constraints. Consequently, DRL methods encounter difficulties in generating feasible solutions for more complex scenarios. In this study, we address these limitations by introducing additional real-world side constraints and exploring diverse mechanisms to accommodate them while steering the search towards feasible solutions. Our experimentation extends to a variety of combinatorial optimization problems, including the Capacitated Vehicle Routing Problem with Time Windows (CVRPTW) and Skill-VRP, showcasing our approach's effectiveness in handling practical constraints.

Optimizing Ambulance Dispatching and Redeployment: A Structured Learning Approach

Maximiliane Rautenstrauß[1], Maximilian Schiffer[1,2]

[1]School of Management, Technical University of Munich; [2]Munich Data Science Institute, Technical University of Munich; maximiliane.rautenstrauss@tum.de

Minimizing response times to serve patients in a timely manner is crucial for Emergency Medical Service (EMS) systems. Achieving this goal necessitates optimizing operational decision-making to efficiently manage available ambulances. Recent efforts focus on developing online ambulance dispatching policies and determining optimal waiting positions for idle ambulances that enable a fast response to future requests. Against this background, we study a centrally controlled EMS system in which the dispatcher must i) dispatch an ambulance upon receiving an emergency call and ii) redeploy it to a waiting location upon the completion of its service. In this context, we aim to learn an online ambulance dispatching and redeployment policy that minimizes the mean response time of ambulances within the system. As a basis, we first present a mixed integer linear program to derive optimal dispatching and redeployment decisions for offline settings. Second, we introduce a machine learning (ML) pipeline enriched by a combinatorial optimization (CO) layer that leverages these optimal solutions by learning an online ambulance dispatching and redeployment policy in a supervised fashion. Within the pipeline, we train an ML predictor to parameterize the problem instances solved subsequently in the CO layer, generating feasible solutions to our original problem instances. We learn a policy by minimizing the non-optimality between the optimal offline solutions and the online solutions derived from the CO layer. To evaluate the performance of the learned policies against current industry practices, we conduct a numerical case study on the example of San Francisco's 911 call data.

WC 03: Advances in Machine Learning

Time: Wednesday, 04/Sept/2024: 1:00pm - 2:30pm · *Location:* Theresianum 0606
Session Chair: Stefan Pickl

A Biobjective Perspective on Physics-informed Neural Networks

Lea Sophie Meissner

Bergische Universität Wuppertal, Germany; 1841450@uni-wuppertal.de

Physics-informed neural networks (PINNs) make data-based predictions using physical laws, typically in the form of differential equations. The PINN approximates the solution, minimizing the data loss, corresponding to deviation from the data, and the residual loss, quantifying deviation from the differential equation, resulting in a biobjective optimization problem. The growing popularity of PINNs is attributed to their robustness on small, noisy datasets, which is particularly desirable for experimental applications. The application of PINNs is not limited to physical phenomena. The seamless integration of domain knowledge into data-driven approaches makes them promising candidates for a wide range of scientific, economic, and engineering applications.

The aim of this study is to design and train a PINN but also to evaluate its performance in the context of data affected by measurement errors and determining missing parameter values of the differential equation. The oscillation of a damped simple pendulum is selected as a case study, offering both evaluation aspects. To distinguish the performance of a PINN from that of a standard neural network, both were implemented as feedforward neural networks and trained using the same variant of the gradient descent method.

The results demonstrate that the systematic selection of hyperparameters enables accurate predictions with PINNs, in contrast to the significant deviation from the data observed for standard neural networks. Training parameter values of the differential equation alongside network parameters enhances accuracy. Random measurement errors are negligible due to regularization, while systematic errors affect the accuracy of the prediction and the determined parameter values.

Non-Normal Distributions: A comparison of Reinforcement Learning Algorithms under various probability distributions

Maximilian Moll, Stefan Pickl

University of the Bundeswehr Munich, Germany; stefan.pickl@unibw.de

Reinforcement Learning algorithms have garnered significant attention for their ability to learn optimal decision-making policies in uncertain and dynamic environments. However, the performance of RL algorithms can vary considerably depending on the underlying probability distributions characterizing the environment. We presents a comprehensive comparison of RL algorithms under various probability distributions, emphasizing the importance of understanding their behavior beyond the typical assumption of Gaussian or normal distributions.

Through experiments across different settings, we explore the performance of popular RL algorithms, including Q-Learning, Deep Q-Networks, and Proximal Policy Optimization, across a range of probability. We investigate how the shape, scale, and skewness of these distributions influence the convergence rate and stability of RL algorithms.

Optimizing Representativeness with a Novel Clustered Sampling Approach for Diverse Populations

Sohrab Mamdoohi

Grubhub, United States of America; smamdoohi@grubhub.com

This work introduces a novel clustered sampling approach aimed at ensuring the representativeness of samples across diverse populations. The method formulates the sampling problem as an optimization problem, with the objective of selecting the best representative sample while accommodating variations in sample characteristics. Through rigorous optimization techniques, the method facilitates informed decision-making processes and supports robust statistical analyses.

Comparison of the results obtained from this method with those of other sampling methods reveals a significantly more representative sample generated by the proposed approach. Notably, the characteristics of the selected sample exhibit the same distribution as the entire network, emphasizing the method's effectiveness in accurately capturing the population's diversity.

Furthermore, this method has been successfully implemented for experimentation purposes in a meal delivery service company. The application of the approach in real-world settings underscores its effectiveness and practical utility in addressing sampling challenges across different industries.

WC 04: Stochastic and Robust Optimization: Theory and Applications

Time: Wednesday, 04/Sept/2024: 1:00pm - 2:30pm · *Location:* Wienandsbau 2999
Session Chair: CAGIL KOCYIGIT

Learning Optimal and Fair Policies for Allocating Scarce Societal Resources from Data Collected in Deployment

Bill Tang[1], Cagil Kocyigit[2], Eric Rice[1], Phebe Vayanos[1]
[1]University of Southern California; [2]University of Luxembourg; cagil.kocyigit@uni.lu

We study the problem of allocating scarce societal resources of different types (e.g., permanent housing, deceased donor kidneys for transplantation, ventilators) to heterogeneous allocatees on a waitlist (e.g., people experiencing homelessness, individuals suffering from end-stage renal disease, Covid-19 patients) based on their observed covariates. We leverage administrative data collected in deployment to design a policy that maximizes expected outcomes while satisfying budget constraints, in the long run. Our proposed policy waitlists each individual for the resource maximizing the difference between their estimated mean treatment outcome and the estimated resource dual-price or, roughly, the opportunity cost of using the resource. Resources are then allocated as they arrive, in a first-come first-serve fashion. We demonstrate that our data-driven policy almost surely asymptotically achieves the expected outcome of the optimal out-of-sample policy under mild technical assumptions. We extend our framework to incorporate various fairness constraints. We evaluate the performance of our approach on the problem of designing policies for allocating scarce housing resources to people experiencing homelessness in Los Angeles based on data from the homeless management information system. In particular, we show that our policies simultaneously improve exit rates from homelessness and enhance fairness compared to historical allocations.

Wasserstein Distributionally Robust Optimization with Heterogeneous Data Sources

Yves Rychener[1], Adrián Esteban-Pérez[2], Juan M. Morales[3], Daniel Kuhn[1]
[1]EPFL; [2]Erasmus University of Rotterdam; [3]University of Málaga; daniel.kuhn@epfl.ch

We study decision problems under uncertainty, where the decision-maker has access to K data sources that carry biased information about the underlying risk factors. The biases are measured by the mismatch between the risk factor distribution and the K data-generating distributions with respect to an optimal transport distance. In this situation, the decision-maker can exploit the information contained in the biased samples by solving a distributionally robust optimization (DRO) problem, where the ambiguity set is defined as the intersection of K optimal transport neighborhoods, each of which is centered at the empirical distribution on the samples generated by a biased data source. We show that if the decision-maker has a prior belief about the biases, then the out-of-sample performance of the DRO solution can improve with K - irrespective of the magnitude of the biases. We also show that, under standard convexity assumptions, the proposed DRO problem is computationally tractable if either K or the dimension of the risk factors is kept constant.

Distributionally Robust Auction Design with Deferred Inspection

Halil Ibrahim Bayrak, Martin Bichler
Technical University of Munich, Germany; halil.bayrak@tum.de

Mechanism design with inspection has received increasing attention due to its applications in the field. For example, large warehouses such as those operated by Amazon have started to auction scarce capacity. This capacity shall be allocated in a way that maximizes the seller's revenue. In such mechanism design problems, the seller can inspect the true value of a buyer, his realized sales in the next period, without cost. Prior work on mechanism design with deferred inspection is based on the assumption of a common prior distribution. We design a mechanism with a deferred inspection that is distributionally robust. We assume a principal who is ambiguity-averse in the sense that she wants to maximize her worst-case payoff from the auction. We consider the single-agent setting and Markov ambiguity sets, which contain all distributions within a fixed support satisfying a constraint on expectation. When the lowest possible expected value is above some threshold, a relatively simple mechanism with a concave allocation rule and a linear payment rule achieves robust optimality. When the lowest possible expected value is under this threshold, we propose an approximate mechanism instead, as the calculation of a robustly optimal mechanism requires solving high-order polynomials.

Efficient Asymptotics for Condition-Based Replacement Thresholds

Poulad Moradi Shahmansouri, Joachim Arts
University of Luxembourg, Luxembourg; poulad.moradi@uni.lu

Condition-based maintenance aims to proactively plan actions to prevent equipment failure while considering economic implications. In this study, we address the problem of a component that experiences degradation with independent stationary increments. Failure occurs when the degradation exceeds a threshold and the degradation is periodically inspected. During each inspection, a decision must be made whether or not to replace the component and an estimate of the remaining useful life can be made for spare part inventory planning. Although this problem has been extensively studied, computing optimal replacement policies requires dynamic programming, which is an obstacle to implementation in practice. To address these issues, we perform an asymptotic analysis of optimal replacement thresholds and cost rates, leading to the development of an efficient replacement heuristic with an asymptotic optimality guarantee. Our extensive numerical experiments show that the average optimality gap of our heuristic replacement policy is at most 0.01% when degradation increments follow a discrete distribution and 0.52% when the distribution is continuous. Notably, the heuristic outperforms the exact algorithm in terms of computational time by a factor of at least 1000. Furthermore, we are extending our analysis to situations where the parameters of the degradation increment distribution are unknown, necessitating a Bayesian learning approach.

WC 05: Methods for Robust and Stochastic Optimization 1

Time: Wednesday, 04/Sept/2024: 1:00pm - 2:30pm · *Location:* Wienandsbau 3999
Session Chair: Baturhan Bayraktar

A gradient-based method for joint chance-constrained optimization with continuous distributions

Daniela Bernhard, **Frauke Liers, Michael Stingl**

Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany; daniela.db.bernhard@fau.de

A common way to model stochastic uncertainties in the constraints are chance constraints. We present a gradient-based algorithm to approximately solve the difficult class of joint chance-constrained optimization problems with continuous distributions and non-convex constraint functions. To apply our method we approximate the original problem by smoothing indicator functions and penalize a violation of the smoothed constraint in the objective function. The resulting approximation problem is solved with the Continuous Stochastic Gradient method that has recently been introduced in the literature. It is a variant of the stochastic gradient descent with improved convergence properties. Under very mild assumptions our approach is applicable to a wide range of joint chance-constrained optimization problems. Its efficiency in practice is illustrated with an application to gas networks. The experiments demonstrate that the approach quickly finds nearly feasible solutions for joint chance-constrained problems with non-convex constraint functions and continuous distributions, even for realistically-sized instances. Additionally, we provide a theoretical convergence theory for the smoothing and penalty approximations with sequences of increasing smoothing and penalty parameters.

Piecewise affine decision rules for multi-stage adjustable optimization

Simon Thomä[1], Wolfram Wiesemann[2], Maximilian Schiffer[3]

[1]RWTH Aachen, Germany; [2]Imperial College Business School, UK; [3]TUM School of Management & Munich Data Science Institute, Germany; simon.thomae@om.rwth-aachen.de

In operations management, making decisions in the face of progressively revealed uncertainty presents a central challenge with vast applications across numerous sectors, including manufacturing, logistics, and finance. Against this background, we study generalized multi-stage stochastic programs that unify several commonly studied problem formulations, including stochastic, robust, and data-driven optimization. To efficiently find solutions for this new problem formulation, we generalize a class of piecewise affine policies that were previously studied for stochastic and robust settings but were not applicable to data-driven settings. While these policies yield significant improvements over affine policies in the stochastic optimization setting, no improvements were observed in the robust setting. We provide theoretical justification for this observation and overcome this shortcoming by introducing a new class of cuts that tightens the piecewise affine policy approximation. While the resulting separation problem is NP-hard in general, we identify favorable properties - fulfilled by many commonly studied uncertainty representations, including budgeted and ellipsoidal uncertainty - that render the problem tractable. Our numerical experiments reveal that our policies' new class of cuts leads to objective improvements over previous policies of up to 10% in data-driven settings and up to 20% in robust settings.

A Stochastic Nested Decomposition for Solving Multistage Stochastic Integer Programming Models with Quadratic Binary Objective Functions

Baturhan Bayraktar, Martin Grunow, Rainer Kolisch

Technical University of Munich, Germany; baturhan.bayraktar@tum.de

Multistage stochastic integer programs are notorious due to their rapidly growing complexity by increasing stages. Several decomposition techniques have been developed using piece-wise convex polyhedra for under-approximating cost-to-go functions. Examples of these techniques include nested decomposition and dual dynamic integer programs. Nevertheless, the performance of these approaches heavily depends on the optimality cut generated in each iteration during the search process. In this study, we develop a new stochastic nested decomposition algorithm for solving multistage integer programs with quadratic objective functions containing binary state variables. We introduce a novel type of Lagrangian cut to improve the algorithm's performance. Furthermore, we enhance the implementation performance by selectively bypassing specific algorithm steps under certain conditions. Our experiments focus on a reconfigurable matrix assembly layout design problem under uncertain demand. We compare our algorithm using the developed Lagrangian cut against classical nested decomposition and extensive mixed integer linear programming formulations solved with commercial solvers. Finally, we analyze the performance changes when the scenario tree incorporates nodes that contain shared child nodes and stage-wise independence.

WC 06: Vehicle Routing

Time: Wednesday, 04/Sept/2024: 1:00pm - 2:30pm · *Location:* Wirtschaftswissenschaften Z534
Session Chair: David Schindl

WasteLogs: a decision support tool for strategic waste collection

Jérôme De Boeck[1], Merixell Pacheco[2], Vera Fischer[3]

[1]University of Liège, Belgium; [2]University of Fribourg, Switzerland; [3]Swiss Post, Bern, Switzerland; jerome.deboeck@uliege.be

Waste collection management has seen an increasing interest in the OR community these past years. This is due to the wide range of Capacitated Vehicle Routing Problems (CVRP) studied and the growing trend in studying sustainability-related problems.

For waste collection companies, it can be challenging to identify the type of strategy most suitable for a given situation. On the one hand, the complexity of the state-of-the-art algorithms presented in the literature; on the other hand, the data needed for these algorithms can be challenging to obtain and encode.

In partnership with Alpenluft, a Swiss waste collection consulting company, and the Innosuisse agency supporting R&D projects, we developed the WasteLogs application, a user-friendly strategic waste collection decision tool. The application offers interfaces allowing the encoding of the collection points, the amounts of waste to collect, and the collection strategy in different features that can be combined to generate a routing for collection vehicles. There are currently three state-of-the-art collection strategies implemented in the tool. Each algorithm minimizes the CO2 emissions through heuristic methods; the user can then identify what collection strategy is the most suitable and extract the information needed to import them into GPS systems. WasteLogs also allows importing existing collection tours to evaluate whether they can be improved.

Data-driven response to dynamic spatio-temporal transportation requests

Sacha Varone, David Paulino

HES-SO University of Applied Sciences and Arts Western Switzerland, Switzerland; sacha.varone@hesge.ch

We consider a decision problem in a transport company. Every day, the company receives transport requests by phone from various customers. A request consists of an origin, a destination and a time window within which the request must be fulfilled. The decision to accept or reject the request must be made within a short timeframe: between a few seconds and a few minutes.

We develop an analytical decision process to accept or reject a request based on expected revenues. We use a geographic information system to calculate transport times and lengths. We use the company's historical data to predict new spatio-temporal requests, using clustering and probability methods. Next, a simulation generates instances of vehicle routing problems, which are solved using heuristics from open-source tools, enabling the expected revenue to be calculated. The request is then accepted or rejected, based on the expected value at the time the request is made. We test our methods on generated data.

A column generation approach for the routing of electricity technicians

David Schindl[1], Elise Bangerter[2], Meritxell Pacheco[2]

[1]University of Applied Sciences Western Switzerland, Haute Ecole de Gestion de Genève, Switzerland; [2]University of Fribourg, Switzerland; david.schindl@hesge.ch

The maintenance of an electricity distribution network involves numerous daily technical interventions. In this problem, we are given a set of interventions each with associated time windows, location, necessary skills and duration, as well as a set of teams of technicians with associated set of skills, each represented by a vehicle. We need to find feasible routes on the interventions for each vehicle, taking into account the time windows and skills, and ensure that each vehicle returns to its departure depot before the end of the day. The primary objective is to maximize the total duration of completed interventions and as a secondary objective, we aim to minimize the overall routing cost. This problem can be formulated as a capacitated vehicle routing problem with time windows. Due to the large number of vehicles and interventions, this results in a large-scale optimization problem, and its operational nature limits the time available for exact solving. Here, we propose a column generation approach where the subproblem decomposes into a subproblem per vehicle and each potential route of a vehicle is considered as a new column in the master problem. To generate these routes, we rely on dynamic programming. Real-world instances from EDF (Electricité de France) of historical technicians' interventions will be used to evaluate the effectiveness of the proposed methods.

WC 07: Mixed Integer Programming

Time: Wednesday, 04/Sept/2024: 1:00pm - 2:30pm · *Location:* Wirtschaftswissenschaften Z536
Session Chair: Andreas Wiese

The Parallel Epsilon Algorithm for tri-objective integer optimization problems

Kathrin Prinz, Stefan Ruzika

RPTU, Germany; prinz.kathrin@math.rptu.de

We present a new algorithm, the Parallel Enumeration Algorithm (PEA), for enumerating the nondominated set of tri-objective integer optimization problems. PEA only requires solving a linear number of lexicographic epsilon-constraint scalarization problems. Furthermore, PEA is easy to implement and easy to parallelize: A novel order on the nondominated set, induced by the structure of the parameter space of the lexicographic epsilon-constraint scalarization is utilized to split the computation into a number of independent parallel tasks, such that no communication between different tasks is required. Consequently, the communication overhead, one of the main factors of diminishing speedups, is minimal.

The performance of the algorithm was evaluated and compared to the CPLEX parallelization of a state-of-the-art sequential algorithm for tri-objective integer optimization problems on benchmark knapsack and assignment problems for up to 16 threads. Additionally, we investigated the scaling of PEA with up to 128 threads. The results of the computational study demonstrate the effectiveness of the proposed algorithm and the computational advantage of its parallelization, as it achieves an almost linear speed-up in the number of threads. Furthermore, the new algorithm outperforms the CPLEX parallelization of the state-of-the-art algorithm as soon as more than two threads are available.

Piecewise Linear Relaxations of Mixed-Integer Nonlinear Programs: A Computational Study

Kristin Braun[1,2], Robert Burlacu[1,3]

[1]Fraunhofer Institute for Integrated Circuits (IIS), Germany; [2]Friedrich-Alexander Universität Erlangen-Nürnberg; [3]University of Technology Nuremberg; kristin.braun@iis.fraunhofer.de

Solving mixed-integer nonlinear problems by means of piecewise linear relaxations can be a reasonable alternative to the commonly used spatial branch-and-bound. These relaxations have been modeled by various mixed-integer models in recent decades. The idea is to exploit the availability of mature solvers for mixed-integer problems. In this work, we compare different reformulations in terms of behavior and runtime to determine which method to apply in practice. To this end, we implement eight different mixed-integer representations for piecewise linear relaxations and evaluate them on a benchmark set from the MINLPLib consisting of over 300 instances. We utilize existing expression trees to reformulate all nonlinearities to one-dimensional functions and afterwards compute a set of interpolation breakpoints for each function based on a given maximum error per segment. Our analysis includes a comprehensive comparison of the number of problems solved, runtimes, and optimality gaps. Overall, the classical incremental method Markowitz and Manne 1957 has the best performance, leading to a general recommendation of this method for solving nonlinear problems by piecewise linear relaxations.

Diversity-Preserving Test Set Size Reduction for Mixed Integer Programming with Structured Problem Instances

Tim Donkiewicz, Marco Lübbecke

RWTH Aachen University, Germany; donkiewicz@or.rwth-aachen.de

Solving mixed-integer programming instances can be a time-consuming endeavor. Acceleration techniques include the exploitation of the problem's underlying structure. By decomposing the problem into subproblems it may be easier, sometimes even computationally efficient to solve. To that end, methods like Benders decomposition or Dantzig-Wolfe reformulation can lead to significant speedups in the solving process. However, the development and evaluation of algorithms that make use of a problem's structure require representative sets of test instances and their structure.

The structured integer programming library (strIPlib) is a public collection of about 40.000 instances and decompositions. Due to its size, it is impractical to use all instances, and the selection of instances can introduce bias and difficulties in the comparability of approaches.

To facilitate meaningful and reproducible research, we compile a benchmark and collection test set, using instance data, decomposition data, and data on the solving behavior, generated by the Generic Column Generation (GCG) solver. Additionally, we present a method to compile customized test sets based on user-defined filters on static and runtime data. The method aims to preserve diversity within filter arguments.

Preliminary results indicate that the benchmark and collection sets are representative (according to our metrics) of the full strIPlib to expected degrees and that the custom test set generation is a powerful tool for targeted experimentation.

StudyPlanner: Helping students to plan university courses with integer programming

Kai Eberl, Ahmed Rayen Mhadhbi, Michael Ritter, Alexander Anthony Tang, Philipp Wiedmann, Andreas Wiese

Technical University of Munich, Germany; andreas.wiese@tum.de

At the beginning of each semester, all university students need to plan the courses they want to take this semester. In the process, they need to take into account the rules of their degree program. Those might, for example, regulate that some courses are compulsory, that one needs to complete a certain number of credits from a group of courses, or that one needs to choose a study focus from some given options. Also, there are additional considerations, such as the preferences of the student for certain subjects, the times when the courses are scheduled, or that some courses need to be taken in a certain order. In particular, it is a good idea to not just plan the courses of the upcoming semester, but all courses in all future semesters.

This leads to an optimization problem with multiple objectives that include, for example, minimizing the time until graduation and maximizing the satisfaction of the student with the selected courses. We propose an integer programming (IP) formulation for this problem and apply it to the Bachelor and Master degree in Mathematics at the Technical University of Munich (TUM). In our computational experiments, we could solve most of the tested instances in about one second using the non-commercial IP solver

SCIP, and even faster with Gurobi. We made our planning tool available to the students of the Department of Mathematics at TUM. It is publicly accessible at https://studyplanner.co.cit.tum.de.

WC 08: Mixed-Integer Nonlinear Programming for Gas Networks

Time: Wednesday, 04/Sept/2024: 1:00pm - 2:30pm · *Location:* Wirtschaftswissenschaften Z538
Session Chair: Julia Grübel

Global Optimization of Gas Transportation and Storage: Convex Hull Characterizations and Relaxations

Bahar Cennet Okumusoglu[1], Burak Kocuk[2]

[1]Technical University of Munich, Germany; [2]Sabanci University, Istanbul, Turkey; bahar.okumusoglu@tum.de

Gas transportation and storage has become one of the most relevant and important optimization problems in energy systems. This problem includes highly nonlinear and nonconvex aspects due to gas physics, and discrete aspects due to control decisions of active network elements. In this work, we study the nonconvex sets induced by gas physics for pipes and compressors. We formulate this problem as a nonconvex mixed-integer nonlinear program (MINLP) through disjunctions. Obtaining locally feasible or global solutions for this nonconvex program presents significant mathematical and computational challenges for system operators. Thus, we propose conic programming relaxations for the nonconvex MINLP formulation. The proposed relaxations are based on the convex hull representations of the nonconvex sets as follows: We give the convex hull representation of the nonconvex set for pipes and show that it is second-order cone representable. We also give a complete characterization of the extreme points of the nonconvex set for compressors and show that the convex hull of the extreme points is power cone representable. We also propose a second-order cone outer-approximation for the nonconvex set for compressors. To obtain global or near global optimal solutions, we present an algorithmic framework based on these second-order conic programming programming relaxations. We illustrate the benefit of our relaxations through extensive computational experiments.

Mixture of Gases in Networks

Pascal Börner, Marc Pfetsch, Stefan Ulbrich

TU-Darmstadt, Germany; boerner@mathematik.tu-darmstadt.de

With the move towards a climate neutral usage, gas suppliers and transport companies have begun to mix a certain percentage of hydrogen into the gas networks. This poses new challenges for the modeling and optimization of gas transport. Therefore, we have developed a model for the mixture of gases on networks. The model is based on an equation of state for the mixture, the stationary isothermal Euler equations and coupling conditions for the flow and the mixture. The equation of state or pressure law which we developed is based on the change of the speed of sound in a mixture of gases. We prove that the gas flow is unique, even in the case of a mixture. This is not trivial since the mixture is changing the flow properties and it is not clear anymore if there exist different network flows with different mixing ratios.

Further, we use the model to solve stationary gas flow problems to global optimality on large networks. Therefore, the model is implemented and solved with the help of the MINLP-solver SCIP. We examined different implementations of the model and their impact on computational performance.

Adjustable Robust Nonlinear Network Design under Demand Uncertainties

Johannes Thürauf[1], Julia Grübel[2], Martin Schmidt[1]

[1]Trier University, Germany; [2]University of Technology Nuremberg, Germany; julia.gruebel@utn.de

We study network design problems for nonlinear and nonconvex flow models under demand uncertainties. To this end, we apply the concept of adjustable robust optimization to compute a network design that admits a feasible transport for all, possibly infinitely many, demand scenarios within a given uncertainty set. For solving the corresponding adjustable robust mixed-integer nonlinear optimization problem, we show that a given network design is robust feasible, i.e., it admits a feasible transport for all demand uncertainties, if and only if a finite number of worst-case demand scenarios can be routed through the network. We compute these worst-case scenarios by solving polynomially many nonlinear optimization problems. Embedding this result for robust feasibility in an adversarial approach leads to an exact algorithm that computes an optimal robust network design in a finite number of iterations. Since all of the results are valid for general potential-based flows, the approach can be applied to different utility networks such as gas, hydrogen, or water networks. We finally demonstrate the applicability of the method by computing robust gas networks that are protected from future demand fluctuations.

WC 09: Competition in Pricing

Time: Wednesday, 04/Sept/2024: 1:00pm - 2:30pm · *Location:* Wirtschaftswissenschaften Z532
Session Chair: Rainer Schlosser

Optimizing Pricing Strategies in Duopolistic Media Platforms: A Study of Cross-Network Effects and Multi-Homing

Ajit Pratap Singh, Suresh Kumar Jakhar

Indian Institute of Management, Lucknow, India; phd21023@iiml.ac.in

Our research delves into the optimal pricing strategy within a duopolistic media platform market, considering the interplay of cross-network effects among viewers, content creators, and advertisers. Employing a game-theoretical linear city model, we analyze the dynamics among these interconnected stakeholders across three sides. Our investigation examines how platform pricing adjusts with the presence of multi-homing on one or more market sides. The insights obtained from our study underscore strategic opportunities for competitive platforms to leverage pricing, differentiation, and cross-network effects effectively to optimize their profits.

We evaluate the relevance of existing literature findings within our context, identifying instances of both alignment and deviation across various scenarios. Our findings suggest that under specific conditions, multi-homing can yield benefits for both market agents and platforms. We explore scenarios wherein multiple sides of the market engage in multi-homing concurrently, proposing that platforms should incentivize one side to multi-home only when other sides also participate in multi-homing. Furthermore, we outline criteria for offering free access or implementing subscription fees for market agents, offering practical guidance for platforms operating within a competitive landscape in the presence of cross-network effects and multi-homing.

On the Existence of Algorithmic Collusion in Dynamic Pricing with Deep Reinforcement Learning

Shidi DENG[1], Maximilian Schiffer[1,2], Martin Bichler[3]

[1]School of Management, Technical University of Munich; [2]Munich Data Science Institute, Technical University of Munich; [3]School of Computation, Information and Technology, Technical University of Munich; shidi.deng@tum.de

Over the past two decades, a significant trend in the business-to-consumer (B2C) sector has been the migration to online platforms like Amazon and Alibaba, relying on Artificial Intelligence (AI) and big data for pricing strategies.

This has sparked debate on whether pricing algorithms may tacitly collude to set supra-competitive prices without explicit programming. Our study addresses these concerns by examining the risk of collusive behavior using Reinforcement Learning (RL) algorithms to decide on pricing strategies in competitive markets.

Prior research in this field focused exclusively on Tabular Q-learning (TQL) and led to opposing views on whether learning-based algorithms can lead to supra-competitive prices. Against this background, our work contributes to this ongoing discussion by providing a more nuanced numerical study that goes beyond TQL by additionally capturing off- and on-policy based deep RL algorithms:

Deep Q-Networks (DQN) and Proximal Policy Optimization (PPO). We study multiple Bertrand oligopoly variants and show that algorithmic collusion indeed depends on the algorithm used. In our experiments, TQL exhibits higher collusion and price dispersion phenomena, while DQN and PPO show lower collusion tendencies. With PPO, in particular, achieving competitive outcomes in a significant share of scenarios. Moreover, our study suggests that continuous action spaces may foster competition by enabling firms to respond more effectively to each other compared to discrete action spaces. Our study also reveals that algorithm dynamics are sensitive to the market environment and general algorithm design decisions, highlighting the complexity of implementing AI in competitive markets.

Reinforcement Learning for Dynamic Pricing Strategies in Competitive Markets with Strategic Customers

Rainer Schlosser, Fabian Lange

University of Potsdam, HPI, Germany; rainer.schlosser@hpi.de

Over the last decades, dynamic pricing has become increasingly popular and challenging. Pricing problems become even more complex if the customer's and competitor's behavior are strategic and unknown. Reinforcement Learning (RL) are a promising approach for solving such dynamic problems with incomplete knowledge. RL algorithms have shown to outperform rule-based heuristics if the underlying Markov decision process used to model market dynamics are kept as simple. Note, this was necessary to calculate optimal pricing policies with traditional solution methods. In this context, in the literature, the customer's behavior is mostly assumed to be myopic. However, the myopic assumption is becoming increasingly unrealistic since technology like price trackers allows customers to act more strategically. In this work, we introduce several types of strategic customers. Specifically, we consider strategic customers who base their purchase decision on past prices and those who anticipate future price development. Further, we investigate whether RL agents are able to cope with strategic consumer behavior. We consider monopoly as well as duopoly markets.

WC 10: Integrated Planning in Health Care

Time: Wednesday, 04/Sept/2024: 1:00pm - 2:30pm · *Location:* Wirtschaftswissenschaften 0514
Session Chair: Clemens Thielen

AI and analytics applied in hospitals: A transparent scoring model for integrated clinical decision and management support

Maximilian Dieing[1], Christina Bartenschlager[2,3], Jens O. Brunner[4]

[1]University of Augsburg; [2]Ohm University of Applied Sciences Nuremberg; [3]University Hospital of Augsburg; [4]Technical University of Denmark; maximilian.dieing@uni-a.de

The intensive care unit (ICU) is a critical and costly asset within hospital settings, necessitating effective management strategies, especially given the influx of emergency cases and the unpredictable nature of patient stays. ICU admissions arise from elective surgeries, further complicating capacity planning. Leveraging artificial intelligence (AI) and analytics as decision support tools presents a promising avenue to address these challenges. However, the practical implementation of such systems remains limited, hindered by factors including digitization gaps and skepticism surrounding AI transparency. This work presents the development and validation of a transparent scoring model utilizing AI and analytics to provide decision support for management in hospitals. Focused on the decision of post-operative ICU transfer for elective surgery patients, our model aims to aid physicians, especially those with less experience, while enhancing capacity planning efficiency through efficient and effective scheduling of elective patients. A comprehensive experiment involving physicians is conducted to evaluate the practical relevance and usability of our transparent scoring model. The results demonstrate that our clinical decision support system accurately predicts ICU requirements, thus optimizing resource utilization and enhancing patient care. In our evaluation data set, approximately 90% of patients are classified correctly. By addressing the gap between AI innovation and practical implementation, this research contributes to the advancement of AI and analytics in healthcare, offering tangible benefits for hospitals striving to navigate resource scarcity and improve patient outcomes.

Steering through uncertainties: dynamic integrated patient-room and nurse-patient assignment in hospital wards

Emily Lex, Fabian Schäfer, Alexander Hübner

Technical University of Munich, Germany; emily.lex@tum.de

Optimizing patient-to-room and nurse-to-patient assignments is crucial for efficient hospital workflows, high-quality care, and patient and staff satisfaction. Integrating both assignment problems enables the optimization of additional objectives that depend on the interaction of the two assignment problems. For example, minimizing the walking distances of nurses or assigning the minimum number of nurses to patients in the same room to mitigate negative effects, such as the spread of infections between rooms by nurses or the disturbance of patients. Existing literature tackles the static version of this integrated problem, assuming full prior knowledge of patient and nurse parameters. However, real-world hospital operations are rife with uncertainties, including patient no-shows, emergency admissions, fluctuating length of stays, and unforeseen nurse absences. Enhancing predictability and forecasting reliability necessitates accounting for stochastic variations within the planning horizon.

We have developed a decision support model that addresses the dynamic patient-to-room and nurse-to-patient assignment. The model is presented as a mixed integer optimization problem. We present an efficient heuristic to solve the assignment problem under data uncertainty. We conduct computational experiments on real-world and artificially generated instances. A comparative analysis against the static problem formulation underscores the efficacy and superiority of our dynamic extensions.

A Literature Review of Operations Research Methods for Patient Transport in Hospitals

Tom Lorenz Klein, Clemens Thielen

Technical University of Munich, Germany; tom.klein@tum.de

Most activities in hospitals require the presence of the patient. Delays in patient transport can therefore cause disruptions and costly downtime in many different areas and departments. This makes patient transport planning a central operational problem in hospitals that should be integrated with other problems such as operating room planning or material transport planning.

This talk presents the first literature review of Operations Research approaches for improving non-emergency patient transport in hospitals. We structure the different patient transport problems considered in the literature according to several main characteristics and introduce a four-field notation for patient transport problems that allows for a concise representation of different problem variants. We then analyze the relevant literature with respect to different aspects related to the considered problem variant, the employed modeling and solution techniques, as well as the data used and the level of practical implementation achieved. Based on our literature analysis and semi-structured interviews with hospital practitioners, we provide a comparison of current hospital practice and the existing literature on patient transport, and we identify research gaps and formulate an agenda for relevant future research in this area.

Enhancing Pandemic Evolution: A Simulation Modeling Study Utilizing German Multicenter Data to Unveil the Value of Federated Machine Learning

Christina C. Bartenschlager[1,2]

[1]Ohm University of Applied Sciences Nuremberg, Germany; [2]University Hospital of Augsburg, Germany; christina.bartenschlager@th-nuernberg.de

The basic idea of Federated Machine Learning is to collect models rather than data centrally. We study the feasibility and the potential of the rather young research area, which has been proposed by Google in 2016, for digital Covid-19 diagnosis based on German multicenter data of 3,670 patients. Therefore, we compare Federated Machine Learning to traditional testing methods such as antigen or PCR (Polymerase chain reaction) tests on economical and operational dimensions. We aim to inform essential decisions regarding the choice of diagnostic methodology during the progression of a pandemic. Accordingly, we run a time dependent simulation for Federated Machine Learning to digitally diagnose Covid-19 and find a significant potential. The federated deep learning model with six clients and full access to all datapoints achieves an F1-score of 89.7 percent. For comparison, the centrally trained model reaches up to 92 percent. Our results highlight the potential of applying Federated Machine Learning to Covid-19 diagnosis. The study might therefore function as a benchmark for hospital managers to contribute to future research while maintaining governance of their data.

WC 11: Behavioral Decisions 2

Time: Wednesday, 04/Sept/2024: 1:00pm - 2:30pm · *Location:* Theresianum 2609
Session Chair: Michael Becker-Peth

How to Account for Behavioral Newsvendors: The Robust Buyback Contract to Address Response Uncertainty

Michael Becker-Peth[1], Kai Hoberg[2], Christina Imdahl[3]

[1]Rotterdam School of Management, Erasmus University, The Netherlands; [2]Kühne Logistics University – KLU, Germany; [3]Technical University Eindhoven, The Netherlands; m.beckerpeth@rsm.nl

The normative (expected profit-maximizing) theory assumes that decision-makers are fully rational, but in reality, they deviate from the optimal response. In contract negotiations, contract parameters are often optimized based on the assumption of rational behavior. Deviations from rational behavior can lead to significant costs for all parties involved. To address this, we propose robust optimization to obtain contract parameters that are robust to deviations from rational behavior.

We apply this optimization approach to obtain the robustly optimal contract parameters for the buyback contract when there is limited knowledge of the buyers' responses.

We compare the robust contract to the normative contract if people behave according to known behavioral models, such as mean-anchoring, bounded rationality, or a behavioral model explicitly for the buyback contract. Additionally, we test different robust contracts in a lab experiment with actual human decision-makers. The results demonstrate that a robust contract, based on simple assumptions, can outperform the normative contract in terms of risk while not sacrificing average supply chain profit. This approach offers a practical way to set contract parameters without relying on assumptions about the distribution of responses, except for the support.

Decision Threshold Preferences in Binary Classification Problems – A Behavioral Lens

Patrick Moder[1], Kai Hoberg[1], Felix Papier[2]

[1]Kühne Logistics University, Hamburg, Germany; [2]ESSEC Business School, Paris, France; patrick.moder@klu.org

When binary classifications are wrong, operations managers face misclassification costs. While false positive outcomes lead to unnecessary mitigation efforts, false negative outcomes imply overlooking the class of interest. Translating the prediction probability into a positive or negative classification can be customized by adjusting the decision threshold, i.e., the cut-off probability. Our study shows that, despite being provided with all relevant information, decision makers do not select the optimal threshold that minimizes misclassification costs. We conducted incentivized, controlled laboratory experiments to investigate which decision problem characteristics and biases explain this boundedly rational behavior. Our findings are twofold. First, participants systematically select sub-optimal thresholds. We observe a significant interaction effect of class and cost imbalance on the deviation from the optimum. The deviation from the optimum increases in high stakes settings where more extreme thresholds would be optimal. Second, we find that the pull-to-center behavior can be explained by an anchoring and insufficient adjustment heuristic. In particular, we show that anchoring on the mean threshold does not explain the behavior sufficiently in settings with cost imbalance. In line with the notion of impulse balance, we find an additional reference point for which the expected misclassification costs for false alarms and missed hits are equal. Our findings suggest that this impulse balance equilibrium also serves as reference point for ex ante decisions and without loss aversion. Operations managers need to be informed about these boundedly rational preferences as sub-optimal decision threshold preferences result in 52% higher misclassification costs, on average.

Improving Human Packing with Standardization: A Behavioral Experiment

Sebastian Schiffels[1], Christian Jost[2]

[1]University of Augsburg, Germany; [2]Technical University of Munich; sebastian.schiffels@uni-a.de

Packaging parcels into delivery vehicles is a central logistic activity and, despite technological advancements, requires the work of human logistics professionals. Here, packing speed and efficiency are key factors, as inefficiencies result in higher transport costs and increased CO_2 emissions. In an experimental study, we investigate how standardized packages influence human packing behavior and efficiency. We examine two opposing effects: Package standardization enhances efficiency by facilitating the easy placement of similarly sized packages, enabling workers to quickly find space-efficient packing solutions. Yet, standardized packaging results in unused space between items and their packaging, decreasing delivery vehicle utilization. The latter is a common phenomenon criticized by customers and media amid the ongoing sustainability debate. Insights from our experiment contribute to this discussion as they shed light on whether the empty space within packages can be sustainable if it boosts human packing efficiency and sufficiently reduces the empty space between packages.

WC 12: Robust and Stochastic MCDM

Time: Wednesday, 04/Sept/2024: 1:00pm - 2:30pm · *Location:* Theresianum 2601
Session Chair: Sven Peters

Parallel implementation of a method for solving the multi-objective stochastic integer optimization problem on a CPU-GPU system

Younes DJELLOULI
National preparatory school for engineering studies(ENPEI), Algeria; jonesdje16@gmail.com

Solving stochastic multi-objective programming, especially when integrated with integer optimization, presents significant challenges, particularly in harnessing parallelism and effectively utilizing CPU-GPU systems to address this issue. Therefore, a critical need arises for a method that can leverage parallel computing capabilities and efficiently utilize CPU-GPU systems to generate all efficient solutions for this complex problem. In this context, we introduce a novel exact approach that integrates two techniques: the l-shaped stochastic two-stage method and the exact method. This combined methodology aims to generate all efficient solutions, particularly in the deterministic case. We assess the performance implications of parallel computing through a specialized numerical demonstration, illustrating the various stages of our computational results. This process involves randomly solving numerous examples to construct a database, ultimately serving as validation for both proposed methods, particularly the parallel one.

Incorporating Uncertainty in Risk Management for Multi-criteria Portfolio Optimization

Yannick Becker
Fraunhofer ITWM, Germany; yannick.b.becker@itwm.fraunhofer.de

In portfolio optimization, balancing risk and return is crucial. Traditional models like the Markowitz often fail to capture the complex nature of uncertainties, leading to inadequate decision-making. Our research advances this by evolving the Markowitz model into a multi-objective framework that simultaneously optimizes multiple aspects such as return, volatility, solvency ratio, and transaction volume. This approach significantly improves asset allocation by addressing challenges from incomplete knowledge and fluctuating parameters in real-world scenarios.

We explore multi-objective robust optimization to bolster decision support and enhance risk management, focusing on uncertainties that impact only volatility parameters amid varying economic conditions. Our methodology, diverging from the typical single objective focus, involves adapting robust optimization to multi-objective scenarios. This innovation offers robust solutions across diverse economic scenarios without relying on probabilistic predictions, focusing instead on minimizing regret relative to a benchmark solution. Our findings indicate that this strategy effectively identifies portfolios that perform well across various scenarios, confirming the value of focusing on areas near the benchmark solution for portfolio managers. This approach not only supports practical application but also opens avenues for further research into optimizing portfolio strategies under uncertainty.

Future work will aim to quantify these strategies further and compare their effectiveness using real asset data, enhancing our understanding of robust multi-objective optimization under partial uncertainty.

Multi-objective adjustable robust optimization in chemical plant design

Katrin Teichert[1], Kerstin Schneider[1], Jan Schwientek[1], Michael Bortz[1], Norbert Asprion[2]
[1]Fraunhofer ITWM, Germany; [2]BASF, Germany; katrin.teichert@itwm.fraunhofer.de

In chemical plant design, the engineer's aim is to determine the most preferable design parameters for a plant layout - such as reactor volume or distillation column diameter, and number of stages - by optimization of a process flowsheet model. The preferability of a plant design is defined by multiple objectives, for example product purities, energy consumption, CO2 emissions or investment and operational costs.

In many instances, external factors (e.g. feed stream conditions, prices or reaction model parameters) are uncertain. These factors influence the objectives at the design stage but their impact will be known when the plant is operated. This allows the operator to react and adjust operational settings such as pressures or reflux ratios during operation. Accounting for this specific type of uncertainty within the general multi-objective nature of the plant design problem results in a multi-objective adjustable robust optimization (MARO) problem.

We present two approaches to solve the MARO problem of chemical plant design. In the sequential approach, the uncertain problem is first treated as an objective-wise worst-case robust problem, and candidate designs with optimal worst-case outcomes are selected. Subsequentially, the adjustability of operational parameters is accounted for, and the (overly pessimistic) outcome prediction of the first phase is refined for the candidate designs. In the decision rule approach, we approximate the dependency of the optimal operational settings on the uncertain factors by affine linear mappings and solve the reformulated problem. We discuss advantages and disadvantages of both approaches and illustrate their usefulness in different planning situations.

Integrating Uncertainties in a Multi-Criteria Decision Analysis with the Entscheidungsnavi

Sven Peters, Mendy Tönsfeuerborn, Rüdiger von Nitzsch
RWTH Aachen University; peters@efi.rwth-aachen.de

The Entscheidungsnavi is an open-source decision support system based on multi-attribute utility theory, that offers various methods for dealing with uncertainties. To model decisions with uncertainties, decision-makers can use two categories: Forecast and Parameter Uncertainties. Forecast Uncertainty is modeled with (combined) influence factors using discrete, user-defined probability distributions or predefined 'worst-median-best' distributions. Parameter Uncertainty allows imprecision for utilities, objective weights, and probability distributions. To analyze these uncertainties, the Entscheidungsnavi offers several methods and tools, like a robustness check, based on (Monte Carlo) simulations and a sensitivity analysis. The objective weight analysis provides insights into the effects of different objective weight combinations. Indicator impacts, tornado diagrams, and risk profiles visualize the impact of uncertainties in a decision under risk. Risk profiles also enable a check for stochastic and simulation dominance. This contribution presents the complete range of methods for dealing with uncertainties in the Entscheidungsnavi using a hypothetical case study.

WC 13: What's new in Solvers

Time: Wednesday, 04/Sept/2024: 1:00pm - 2:30pm · *Location:* Theresianum 2605
Session Chair: Mario Ruthmair

What is new in the SCIP Optimization Suite 9.0

Ksenia Bestuzheva
Zuse Institute Berlin, Germany; bestuzheva@zib.de

The SCIP Optimization Suite is a set of packages for modeling and solving a large variety of optimization problems. At its center is SCIP, an open-source optimization solver for mixed-integer linear and nonlinear optimization problems and a constraint integer programming framework based on a branch-cut-and-price algorithm. This talk will present the developments introduced in SCIP 9.0, including significant improvements and restructuring of symmetry handling, new cutting planes for signomial expressions and a Lagromory cutting plane separator, new primal heuristics, cut selection strategies and branching rules. The presentation will also discuss new features in SCIP-SDP, and new interfaces.

Recent Progress in the Cardinal Optimitzer

Nils-Christian Kempke
COPT GmbH/Cardinal Operations; kempke@copt.de

In this talk, we present the recent developments in the Cardinal Optimizer (COPT). We discuss some key techniques that contributed to the performance improvements of our MIP solver and present performance numbers of the latest COPT release for all problem classes.

Recent Improvements in FICO® Xpress

Gregor Hendel
FICO Xpress Optimization, Germany; gregorhendel@fico.com

In this presentation, we will give an overview of the latest enhancements, the newest features, and the most recent performance improvements in the FICO® Xpress Solver for mixed-integer linear and nonlinear optimization problems. These include a new, first-order hybrid gradient algorithm for linear optimization problems, new heuristics, cutting and branching techniques, an augmented API, and updates to our global MINLP solver.

What's New in Gurobi 11?

Mario Ruthmair
Gurobi Optimization; ruthmair@gurobi.com

We overview recent enhancements, new features, and performance improvements in our Gurobi 11 release.

In particular, we present our new global MINLP solver in more detail. Previously, non-linear terms have been statically approximated by piecewise linear functions. Now, spatial branching with dynamically adapted outer approximation constraints ensures global optimality, subject to tolerances.

Additionally, our automatic parameter tuning tool, in combination with the Gurobi Cluster Manager, has been improved to dynamically and equally re-distribute Compute Server nodes to all running jobs.

WC 14: Optimization and Modeling in Production

Time: Wednesday, 04/Sept/2024: 1:00pm - 2:30pm · *Location:* Theresianum 2607
Session Chair: Benedikt Schulz

A two-dimensional multi-criteria bin packing problem in the production of printed circuit boards

Jochen Rethmann, Steffen Goebbels, Mark Hloch

Hochschule Niederrhein, Germany; jochen.rethmann@hsnr.de

The classical two-dimensional bin packing problem is to put small rectangular items into larger rectangular bins without overlapping, so that the items are completely inside a bin and a minimum number of bins are used. In this paper we want to study a variant where the items have a given demand, i.e. the bins must contain a certain number of copies of each item type. In addition, the number of layouts should also be minimized in order to reduce changeover times. A layout is an arrangement of items within a bin. The primary optimization goals are to minimize the number of bins used and the different layouts. To achieve these goals and to better utilize the occupied area of the bins, additional optional items can be used. However, the use of these optional items is associated with costs. We also have to consider distance constraints. Each item must be separated from all other items and from the bin boundaries by a given distance associated with the item. The problem was motivated by the company Precoplat/MicroCirtec GmbH based in Krefeld, Germany, in an effort to reduce changeover times and waste in multi-layer printed circuit board production.

Flexibility Management in a Laboratory-Scale Microgrid Using Distributed Optimization

Sascha Birk[1], Saber Talari[2], Wolfgang Ketter[2], Thorsten Schneiders[1]

[1]University of Applied Sciences Cologne, Germany; [2]University of Cologne, Germany; sascha.birk@th-koeln.de

The energy transition entails a shift from a centralized electrical generation system comprising a few large power plants to a distributed energy resource (DER) landscape comprising millions of grid-connected DERs across various grid levels. The distributed nature of this future energy system necessitates the development of operation and control algorithms that reflect this trend. Consequently, a growing research stream is emerging in the area of distributed optimization algorithms. In particular, when dealing with DER in medium- and low-voltage grids, the local grid infrastructure plays a crucial role in determining the physical limitations of the desired algorithms. Optimizations have been developed that inherit the grid constraints and prevent congestion. In this work, component-based dual decomposition is used to separate the nodes and lines in a grid, leaving separate optimization problems for the individual nodes and a problem set for the lines. This reflects the individual agents at the nodes and the grid operator. The optimization is implemented as a distributed time series optimization algorithm to account for battery electric storage systems at the nodes and is solved using consensus "Alternating Directions Method of Multipliers". The algorithm is implemented in a laboratory-scale microgrid. The experimental setup is designed to orchestrate the available flexibility in the microgrid in order to provide grid services to the local or upstream grid. Possible improvements to the convergence behavior are analyzed. Furthermore, the results of the communication impact on the algorithm and management of reactive power are presented.

Modelling and performance analysis of different multi-load automated guided vehicle designs

Benedikt Schulz

Karlsruhe Institute of Technology, Germany; benedikt.schulz@kit.edu

Since many years, automated guided vehicles (AGVs) are used in industry to realize transport tasks. Additionally, many methods for planning and control of AGVs have been proposed in literature. While most AGVs are designed to transport a single load, multi-load AGVs gained increasing interest in recent years. They are able to transport multiple loads simultaneously resulting in more complex planning and control compared to single-load AGVs. With regard to material handling of multiple loads, the arrangement of the loads on a multi-load AGV is of particular importance when it comes to operations. The way multiple loads can be arranged depends on the design of a multi-load AGV which might entail loading constraints. For example, loads may be stacked on top of each other, restricting material handling of loads that are located below others.

To evaluate the performance of different multi-load AGV designs, we first formalize and present different design options. Second, we introduce a modular optimization problem which handles the purpose of scheduling multi-load AGV operations and allows to consider different designs. To achieve results for the optimization problem, we third present a solution approach that enables to address the computational complexity of large problem instances. Based on results from numerical experiments, we then analyse the performance of different multi-load AGV designs. On the basis of this performance, we finally derive insights and recommendations regarding planning and control of multi-load AGVs with different designs.

WC 15: Resilient Supply Chains

Time: Wednesday, 04/Sept/2024: 1:00pm - 2:30pm · *Location:* Wirtschaftswissenschaften 0534
Session Chair: Dmitry Ivanov

Two-Stage Supplier Financing under Liquidity Shocks

Nina Yan, Hechen Zhong, Lima Zhao
Stockholm University, Sweden; lima.zhao@sbs.su.se

Utilizing game theory, we examine how a capital-constraint supplier optimizes profit through a two-stage supply chain finance, including purchase order financing and factoring, when confronting potential exogenous liquidity shocks. We analyze suppliers' strategic decisions on whether responding to shocks in two stages and their impact on overall supply chain profitability.

Financing supply chain resilience

Sairam Sriraman[1], David Wuttke[1], Andreas Gernert[2], Volodymyr Babich[3]
[1]TUM School of Management, HN Campus, Germany; [2]Kühne Logistics University; [3]McDonough School of Business, Georgetown University; david.wuttke@tum.de

We examine how financing arrangements and frictions affect supply chain resilience investments. In our game-theoretic model of a buyer, a supplier, and a bank, the supplier can invest in resilience, which reduces the supplier's production losses in case of a shock. The supplier is financially constrained and faces two financing frictions: moral hazard costs (the resilience investment is unobservable) and bankruptcy costs (future cash flows are lost in bankruptcy). We compare two financing arrangements: Under commercial loan financing, the supplier requests a loan from the bank; under buyer-intermediated financing (BIF), the supplier also obtains a loan from the bank, but the buyer guarantees the repayment and proposes the loan terms. Under commercial loan financing, we find that moral hazard costs can lead to credit rationing, limiting the supplier's resilience investments. In contrast, bankruptcy costs can accentuate these investments and change the direction of the moral hazard effect on investments. Bankruptcy costs can even motivate the supplier to invest more in resilience than she would without financing frictions. The buyer benefits from resilience and offers BIF only if it mitigates credit rationing. When BIF is offered, it always increases resilience. Surprisingly, financing frictions can increase the expected value for one of the firms: either the buyer or the supplier. The supplier's bankruptcy costs benefit the buyer when the supplier uses a commercial loan. Moral hazard costs can benefit the supplier when they motivate the buyer to offer BIF.

Balancing Resilience and Sustainability in Supply Chain Design: A Multi-Objective Framework for Climate Change Adaptation

Ari Carisza Graha Prasetia, Luca Urciuoli
KTH Royal Institute of Technology, Sweden; aricgp@kth.se

The built environment is developing building codes and regulations to adapt to climate change, e.g. to factor in increased flooding risks, stronger wind loads, and extreme heat events. This implies the usage of new technologies to be integrated into buildings or infrastructure (e.g. sensors to monitor structural health), or changes in material selection (self-sensing concrete, biomass-based insulation materials, etc.) and construction practices (bioswales to mitigate heat island effects, stilt-elevated structures to protect from flooding, etc.), impacting supply chains. To mitigate these climate-induced disruptions, urban planners are challenged to design and plan supply chains that can optimally trade-off resilient and sustainable objectives. Two key elements of this planning are 1) proactivity in constructing climate-adapted buildings and strategic upgrades of existing vulnerable infrastructure, and 2) contingency plans for rapid response and recovery from infrastructure failures due to unforeseen climate events. This study presents a simulation-optimization framework for resilient and sustainable supply chain design, integrating economic, environmental, social, and resilience considerations. The framework includes a GIS-based spatio-temporal analysis of climate-induced demand for infrastructure upgrades and a multi-objective model. The model is applied to the case of Barcelona's road network renovation, using Nature Based Solutions and recycled glass asphalt to mitigate the heat island effect. The model's robustness and scenario performance are demonstrated through sensitivity analyses. This study contributes to the field by presenting a simulation-optimization framework for resilient and sustainable supply chain design in the face of climate change. The model's application to Barcelona's road network renovation demonstrates its practical utility and robustness.

Identifying hidden critical nodes in supply chains for resilience analysis using simulation and network science

Phu Nguyen, Dmitry Ivanov
HWR Berlin, Germany; phu.nguyen@hwr-berlin.de

Our study employs a combination of network science and simulation techniques to reveal the hidden critical nodes in a supply network, empowering firms to make informed decisions for resilience strategies. We examine a product-level supply network and reveal that a disruption at a medium purchasing volume supplier could induce more significant consequences than a disruption at suppliers with high purchasing volumes. We apply a linear regression model to validate the non-linear relationship between node strength and lost sales, as well as between node strength and Time-To-Survive (TTS). Metrics such as weighted betweenness, weighted eigenvector, and weighted Katz centrality are used for analysis. The insights of our study offer practical implications for supply chain managers to identify the most vulnerable nodes within the network. Moreover, the proposed technique allows for quantifying TTS without relying on supplier data contributing to the resilience assessment methods.

WC 16: Strategic Production Planning in Automotive Supply Chains

Time: Wednesday, 04/Sept/2024: 1:00pm - 2:30pm · *Location:* Wirtschaftswissenschaften 0540
Session Chair: Grit Walther

Optimizing a Worldwide-Scale Load Plan Design Problem in a Carmaker Supply Chain

Mathis Brichet[1,2], Axel Parmentier[1], Maximilian Schiffer[3]

[1]Ecole des Ponts ParisTech, France; [2]Renault, France; [3]Technical University of Munich, Germany; mathis.brichet@enpc.fr

This work is the fruit of a partnership with Renault. Their inbound supply chain is designed to transport car parts from suppliers spread worldwide to dozens of manufacturing plants through logistics platforms. This logistics operation represents roughly a billion euros and tens of thousands of tons of CO2 emissions per year. Optimizing Renault's logistics network in the long run is therefore crucial. The first step is to optimize the flow of car parts. The resulting problem is a rich version of a multicommodity network flow problem, the load plan design problem. Its computational difficulty stems from its combinatorial nature, the combination of a large time-expanded network, hundreds of thousands of arcs, several millions of commodities to be routed, and the practical necessity to consider bin-packing consolidation explicitly. Although recent resolution methods from the literature scale to very large networks, they do not address more than a fifty thousand commodities and do not consider bin-packing constraints. We model this load plan design problem and propose two tailored heuristics to solve it. The first one bases on a Large Neighborhood Search algorithm, combining existing ideas from the literature and custom perturbations to obtain high-quality solutions. The second one bases on a learned decomposition of the problem to solve it much faster, and responds to an industrial need to interact with the algorithm to test and improve some strategic decisions. We provide a data analysis of Renault's instance and a lower bound to analyze algorithm performance. Our numerical experiments show significant improvement over Renault's current solution.

A hybrid heuristic to solve multi-project, multi-mode, multi-criteria resource leveling problems for the strategic planning of new product introductions

Christopher V. Bersch[1], Renzo Akkerman[2], Rainer Kolisch[1]

[1]TUM School of Management, Technical University of Munich; [2]Operations Research and Logistics Group, Wageningen University; Christopher.Bersch@tum.de

Timing the introduction of new products to the market is an important strategic decision in the automotive industry. Due to many technical and organization interactions, it is also a complex decision problem that, when approached with mathematical programming, leads to prohibitively long computation times. To adequately support decision makers in advanced what-if analysis, a solution procedure is required that can solve this problem in shorter time and hence allows for its application in a more interactive manner.

In the literature, hybrid algorithms have proven to be adequate solution procedures in such settings, combining features of exploration and exploitation. However, to the best of our knowledge, none of the presented algorithms has addressed the multi-project, multi-mode, multi-criteria resource leveling problem with generalized precedence constraints that forms the structure of the decision problem we study.

In this presentation, we develop a random key genetic algorithm hybridized with a local search routine to solve the problem described above. We provide an overview of its performance when applied to well-known benchmark instances and outline future research directions.

A Decision Support System for Strategic Product Portfolio Planning of a Car Manufacturer

Marc Helmer, Grit Walther

Chair of Operations Management, RWTH Aachen University, Germany; marc.helmer@rwth-aachen.de

Due to different reasons, the automotive industry is perceiving a massive transition. The shift from ICE to BEV, instable supply chains as well as changed customer demand in the field of digital user experience force car manufacturing companies to adapt their product portfolio more regularly than before. So far, the planning procedure is based on decisions of the involved departments that are partly based on manual calculation of experts, and only partly supported by descriptive analytics. As a conclusion, scenario calculations require long durations and cause high workload.

Hence, we develop a decision support system (DSS) for the strategic product portfolio planning of a car manufacturer based on a MILP integrating the different planning perspectives and requirements. Determining the optimal product portfolio and timing the introduction of the products to the market is one of the most important decisions of the automotive industry. Based on the product architecture, many interdependencies and many interactions between different vehicles must be considered (building blocks, modules, platforms). Moreover, projects rely on shared resources (e.g. financial budgets, development resources, production capacities, etc.), and thus show interdependencies.

The DSS we present allows to calculate and analyze various scenarios based on the formulated MILP. Furthermore, the DSS is designed to be used directly by the decision makers in order to increase data transparency and solution quality. Currently, we are establishing the system within a large car manufacturer in a stepwise process considering different aspects of change management to align to the specific organizational circumstances of the company.

WC 17: Project Scheduling

Time: Wednesday, 04/Sept/2024: 1:00pm - 2:30pm · *Location:* Wirtschaftswissenschaften 0544
Session Chair: Norbert Trautmann

Polyhedra and Complexity Results for the Multi-Mode Project Scheduling Problem

Maximilian Kolter, Martin Grunow, Rainer Kolisch
Technische Universität München, Germany; max.kolter@tum.de

The project scheduling problem without resource constraints arises as subproblem in lower-bound computations such as lagrangian relaxation and column generation for resource-constrained project scheduling problems. Due to this relevance the structure of time-indexed integer programming formulations has been studied extensively for the classical single-mode case. However, for more general multi-mode problems such results are missing. This work contributes to closing this gap by generalizing the following two results to the multi-mode setting: The multi-mode project scheduling problem (i) possesses the integrality property and (ii) is solvable in polynomial time. We prove these results by a transformation into a stable set problem in a perfect graph.

Solving the Resource-Constrained Project Scheduling Problem with Lazy Constraints from Dual Redundant Resources

Alexander Tesch
Bool AI, Germany; tesch@boolai.com

We study the Resource-Constrained Project Scheduling Problem (RCPSP) which has remained one of the most computationally challenging scheduling problems to solve in practice over the last decades. A powerful state-of-the-art method to address this problem is lazy clause generation in combination with energetic propagators to quickly prune variable assignments in which a certain amount of jobs cannot be scheduled within a given time interval. Most energetic approaches from the literature however work only on one resource at a time while the RCPSP considers multiple resources simultaneously. In this talk, we will present an approach to compute additional stronger resources that originate from a dual LP formulation that incorporates the multi-dimensional nature of the resource constraints. We include such “redundant” resources into the energetic propagators to generate stronger lazy constraints. We implemented this method into our constraint programming solver LazyCP and will present insightful results on the RCPSP instances of the classical PSPLIB.

Resource-constrained project scheduling under workload-balancing constraints

Nina Ackermann, Tamara Bigler, Norbert Trautmann
University of Bern, Switzerland; norbert.trautmann@unibe.ch

A single-item or small-series production environment can be represented as a project consisting of a set of precedence-related activities that require time and resources to be performed. The resources represent, for example, production personnel. We present a mixed binary linear program for minimizing the makespan subject to workload balancing constraints.

WC 18: Optimisation and Incentive Mechanisms for Load Applications in Electricity Systems

Time: Wednesday, 04/Sept/2024: 1:00pm - 2:30pm · *Location:* Theresianum 0601
Session Chair: Hannes Hobbie

Investigating incentive mechanisms for grid-serving demand-side behavior under application of bi-level programming

Jannis Eichenberg[1], Hannes Hobbie[1], Tizian Schug[2]

[1]Technische Universität Dresden, Germany; [2]Technische Universität Hamburg, Germany; jannis.eichenberg@tu-dresden.de

Transmission grid congestion management (CM) involves transmission system operators (TSO) adjusting the market-based dispatch of individual generators to address transmission grid constraints cost-effectively.

Growing grid stress from renewable energies and increasing demand from flexible sector coupling technologies calls for innovative CM solutions to handle future grid bottlenecks efficiently. Flexible demand-side applications not only strain electricity grids further but can also provide TSOs with new means for CM. Since directly controlling decentralized demand-side technologies constitutes a complex task considering the information and communication requirement, incentive mechanisms might be a promising solution for leveraging the demand-side flexibility potential for CM.

This work investigates different incentive schemes to stimulate grid-serving demand-side behavior by applying bi-level programming. We benchmark their economic efficiency for resolving grid congestion against the TSO's direct control of demand-side applications. The incentive mechanisms studied assume different design options for a flexibility premium paid to aggregators managing the energy procurement in charge of households, typically owning the flexible demand-side applications. We apply a case study based on a test grid comprising 118 electricity grid nodes, 114 demand-side applications as well as 72 different generators. The formulated bi-level program provides a model-theoretic and techno-economic framework for describing the different decision levels and interactions between the stakeholders involved. These include a TSO, an aggregator, and a market clearing agent.

Initial results of our study indicate that incentive schemes can lead to a significant cost reduction for CM, provided that respective schemes are designed to be time-dynamic.

Cap it or trade it? Efficient design of regional flexibility markets for congestion management considering strategic behaviour of aggregators

Hannes Hobbie[1], Ramteen Sioshansi[2], Dominik Möst[1]

[1]TUD Dresden University of Technology, Germany; [2]Carnegie Mellon University, USA; hannes.hobbie@tu-dresden.de

The increasing electrification of the mobility and heating sectors in future decentralised energy systems necessitates innovative approaches for managing grid congestion. Regional flexibility markets are becoming pivotal for market-based flexibility coordination between grid operators and suppliers. These markets facilitate the required interaction but also introduce challenges related to market design and stakeholder behaviour, which can significantly influence the efficiency of congestion management solutions.

A critical concern in these markets is the potential for strategic gaming behaviours that exploit the locational nature of grid congestion and regional flexibility trading. This study employs bilevel programming techniques to address this issue and analyse the strategic interactions between aggregators and the resultant market dynamics under various market design scenarios.

We introduce a dynamic price cap scheme designed to optimise the trading of demand-side flexibility products. This mechanism aims to promote flexibility provision by aggregators while preventing the exploitation of gaming strategies. Through this approach, we seek to maintain a competitive and efficient market environment that aligns with the overarching goals of enhanced grid reliability and reduced congestion.

This research contributes to understanding how different market design elements can influence the behaviour of key stakeholders and the overall performance of regional flexibility markets in the context of future electricity systems.

Energy Management Optimization on the Basis of Energy Aggregators

Kai Hoth[1], Béla Wiegel[2], Tizian Schug[1], Kathrin Fischer[1]

[1]Institute for Operations Research and Information Systems, TUHH, Germany; [2]Institute for Electrical Power and Energy Technology, TUHH, Germany; kai.hoth@tuhh.de

In this work, a new holistic MILP model for the day-ahead energy management of Energy Aggregators (EAs) is developed. Synergies between the different types of flexibility and energy trading options enable profit maximizing EAs to provide economic benefits to participating households but require a detailed consideration of technological properties and constraints of the respective types of resources and their operation. Therefore, in addition to other types of energy resources, power-to-heat-systems are integrated and modeled on a high level of detail. This represents an important contribution to previous works on EAs and comprises high potential for more efficient energy management. Moreover, three different trading-levels are considered. The model application to a case study with up to 111 individually modeled prosumer-households in summer and winter scenarios reveals high synergetic potential of EAs resulting from the combined flexibility of the different system components, thus underlining the significance of holistically modeling the EA decision problem. A trade-off regarding the flexible usage of energy storages is identified between household battery storages and electric vehicle batteries as their respective technical and practical restrictions are shown to have different advantages depending on external conditions. In addition to assessing the impact of different types of energy resources, analyses are deployed to develop operational strategies towards a foresighted use of energy storages. The results show that the concept of EAs is suitable for efficiently performing energy management for communities of small-scale prosumers with renewable energy sources and has the potential for being an important element in future energy systems.

Exploring Economic Feasibility of Power-to-Hydrogen Solutions for Congestion Management in Medium Voltage Distribution Networks

Sina Ghaemi[1], Machiel Mulder[2]

[1]Department of Energy, Aalborg University, Denmark; [2]Faculty of Economics and Business, University of Groningen, the Netherlands; sigh@energy.aau.dk

Nowadays, the congestion rate in medium voltage distribution networks (MVDNs) is increasing due to higher integration of renewables, highlighting the importance of developing solutions to deal with this issue. Despite of this fact that upgrading the grid can resolve this problem, it is costly and time-consuming. Therefore, more flexible solutions are needed. This paper explores to what extent producing green hydrogen through power-to-hydrogen (P2H) facilities can help alleviate congestion in such grids, considering other flexible sources. To achieve this aim, a bi-level model is proposed: in the upper level, the grid operator seeks to minimize grid costs, while in the lower level, different flexible sources optimize their operational costs, considering the incentives received from the grid operator. In addition, the decentralized district heating system is considered, addressing how the flexibility derived from this system can influence the operation of P2H units as well as the operating costs of the MVDN. The proposed model is implemented in a typical MVDN in the Netherlands, which is equipped with a district heating system. Based on the results, it can be expected that the operation of the electrolyzer will increase by receiving incentives from the grid and by participating in the local heat market to sell their excess heat. Furthermore, the economic value of producing flexibility is more likely to diminish in the presence of more flexible resources in the grid.

WC 19: Near Optimal Solutions and Open Frameworks

Time: Wednesday, 04/Sept/2024: 1:00pm - 2:30pm · *Location:* Theresianum 1601
Session Chair: Jochen Martin Madler

Integrating Machine Learning in Measuring Multidimensional Energy Poverty: New Insights from a Survey Analysis in Europe

Rahil Dejkam, Reinhard Madlener

Institute for Future Energy Consumer Needs and Behavior, Germany; rahil.dejkam@eonerc.rwth-aachen.de

Energy poverty, a multidimensional socio-economic challenge, significantly affects the welfare of many people across Europe. This paper aims to alleviate energy poverty by exploring sustainable energy practices and policy interventions, using household survey data from Portugal and Denmark. A Multidimensional energy poverty index (MEPI) is developed to assess energy poverty through different dimensions such as heating and cooling comfort, financial strain, access to energy-efficient appliances, and overall health and well-being. In a next step, for selecting features, machine learning techniques are employed including recursive feature elimination and random forest analysis. These methods help to reduce the number of irrelevant and mutually correlated predictors. Subsequently, a logistic regression model is used to predict energy-poor households based on selected socio-economic, and policy-related factors. The logistic regression results indicate that sustainable energy-saving behaviors and supportive government policies can mitigate energy poverty. Furthermore, for analyzing the impact of determined features the Shapley additive explanations (SHAP) method is being utilized. Finally, the main findings are evaluated further via scenario simulation analysis. The result shows that fully adopting waste-compositing and energy-efficient microwave ovens can decrease the proportion of energy-poor households by 93% and 79%, respectively. This paper contributes to the literature by providing a thorough analytical framework that enables to identify key features for alleviating energy poverty via effective policymaking and promoting energy-conscious consumption. Its framework can be also applied for studying broader implications in other regions of Europe.

Warm-starting modeling to generate alternatives for energy transition paths in the Berlin-Brandenburg area

Niels Lindner, Karolina Bartoszuk, Srinwanti Debgupta, Marie-Claire Gering, Christoph Muschner, Janina Zittel

Zuse Institute Berlin, Germany; lindner@zib.de

Energy system optimization models are key to investigate energy transition paths towards a decarbonized future. Since this approach comes with intrinsic uncertainties, it is not sufficient to compute a single optimal solution to provide a profound basis for decision makers. The paradigm of modeling to generate alternatives enables to explore the near-optimal solution space to a certain extent. However, large-scale energy models require a non-negligible amount of computation time to be solved. We propose to use warm start methods to accelerate the process of finding close-to-optimal alternatives. In an extensive case study for the energy transition of the Berlin-Brandenburg area, we make use of the sector-coupled linear programming oemof-B3 model to analyze several scenarios for the year 2050 with a resolution of one hour and up to 100% reduction of greenhouse gas emissions; and we demonstrate that we can actually achieve a significant computational speedup.

DistGridGym: An OpenAI Gym-like Framework for Intelligent Agents in Decentralized Power Markets

Jochen Martin Madler[1], Ram Rajagopal[2], Maximilian Schiffer[1]

[1]Technical University Munich, Germany; [2]Stanford University, USA; jochen.madler@tum.de

The electrification of buildings and transportation is one of the key pillars to combat climate change by reducing carbon emissions. The rapid growth of distributed energy assets such as rooftop solar, heat pumps, and electric vehicles necessitates a more decentralized grid architecture. In this context, local electricity markets can facilitate the integration of distributed energy assets and enhance their utilization by aligning distributed generation with consumption. However, existing market designs lack either realistic models of intelligent agents or physical grid constraints, or both. To this end, we propose an opengate forward market design that integrates realistic grid constraints by solving a security constraint optimal power flow problem using linear AC power flow approximation. The market is implemented as an open-source simulation framework based on the OpenAI Gym environment. This Python-based environment allows for the seamless integration of residential agents with state-of-the-art decision-making algorithms. To demonstrate the effectiveness of the proposed framework, we compare two optimization techniques, mixed integer linear programming, and deep reinforcement learning, for solving the residential agent energy management control problem. The first experiment examines the performance of the reinforcement learning optimizer under perfect forecasts, using the linear programming solution as an upper bound. The second experiment examines the robustness of the optimizers to uncertainty by comparing their performance under different degrees of forecast uncertainty. Finally, we present the potential of the proposed framework to support future research on multiagent dynamics, strategic bidding behavior, and the impact of intelligent agents on grid infrastructure.

WC 20: Climate Uncertainty and Risks

Time: Wednesday, 04/Sept/2024: 1:00pm - 2:30pm · *Location:* Theresianum ZG 0670
Session Chair: Leonie Sara Plaga

Stochastic expansion planning of the energy system under electric vehicle charging strategies and charging infrastructure deployment uncertainty

Fabia Miorelli, Shima Sasanpour, Hans Christian Gils, Patrick Jochem

German Aerospace Center (DLR), Germany; Fabia.Miorelli@dlr.de

Strategies for decarbonising large-scale energy systems have a decisive impact on future energy costs and must, therefore, be thoroughly evaluated. Energy systems optimisation models (ESOMs) are frequently employed in the analysis and planning of energy systems. However, their scope and detail in terms of space, time, technologies, and economic sector can vary widely. Due to computational limitations, they can either have a high-resolution scope or a broader less detailed scope in the spatial and temporal dimensions. Stochastic optimisation is a method that offers the possibility to include uncertainties for time-varying inputs within different scenarios, which could represent, for example, different weather or demand profiles. When it comes to demand-side flexibility in the energy system, battery electric vehicles (BEVs) represent a source of uncertainty when considering long-term future energy scenarios. Against this background, this work analyses the influence that different charging infrastructure deployment scenarios and varying BEVs charging strategies (uncontrolled, load shifting and/or vehicle-to-grid) may have on the system design and operation that results from an ESOM. The results highlight these effects in the case of BEVs for the case study of the German energy system in 2050, by including uncertainties through stochastic optimisation.

Asset Pricing with Disagreement about Climate Risks

Marco Thalhammer[1], Thomas Lontzek[1], Walter Pohl[2], Karl Schmedders[3], Ole Wilms[4]

[1]RWTH Aachen University, Germany; [2]NHH Bergen, Norway; [3]IMD Lausanne, Switzerland; [4]University of Hamburg, Germany; marco.thalhammer@rwth-aachen.de

This paper analyzes how climate risks are priced on financial markets. We show that climate tipping thresholds, disagreement about climate risks, and preferences that price in long-run risks are crucial to an understanding of the impact of climate change on asset prices. Our model simultaneously explains several findings that have been established in the empirical literature on climate finance. That is to say, (i) news about climate change can be hedged in financial markets, (ii) the share of green investors has significantly increased over the past decade, (iii) investors require a positive, although small, climate risk premium for holding “brown” assets, and (iv) “green” stocks outperformed “brown” stocks in the period 2011–2021. Furthermore, the model can explain why investments in mitigating climate change have been small in the past. Finally, the model predicts a strong, non-linear increase in the marginal gain from carbon-reducing investments as well as in the carbon premium if global temperatures continue to rise.

Assessment of climate uncertainty in an integrated European power and heating system

Leonie Sara Plaga, David Huckebrink, Valentin Bertsch

Ruhr-Universität Bochum, Germany; leonie.plaga@ruhr-uni-bochum.de

Defossilizing energy systems to mitigate climate change is a complex task. Energy system models can support decision-makers in this endeavor. However, despite efforts to mitigate climate change, Earth's temperature will rise, and changes in the climatic system will influence energy systems. Furthermore, the future climate's development is highly uncertain due to atmospheric complexity and uncertainties in the development of human greenhouse gas emissions.

In this study, we examine the influence of climate change on the European energy system, with a particular focus on residential heating. As temperatures rise, residential heating and cooling demands will change. To address this, we combine a model of the European power system with a building model. The building model utilizes climate projection temperatures as input data, reflecting the impact of climate change on residential heating. By integrating this with the power system model, we can analyze how the heating sector affects the power sector's development.

To assess uncertainty arising from climate projections, we compare different methods. We employ a novel time series clustering algorithm that selects representative days which reduce the amount of unmet demand compared to conventional clustering approaches. We then compare these results to classical robust optimization implemented with a column and constraint generation algorithm.

The model results will illustrate a European heating and power system robust to various climate developments, thereby supporting the energy transition in both sectors.

WC 21: Airport and Airline Applications 2

Time: Wednesday, 04/Sept/2024: 1:00pm - 2:30pm · *Location:* Nordgebäude ZG 1070
Session Chair: Jörn Serrer

Reducing CO2 Emissions in Aviation by Aircraft Sharing and Passenger Bundling Between Airlines

Yiwen Zhu[1], Thomas Hagspihl[1], Rainer Kolisch[2]

[1]Bauhaus Luftfahrt e.V., Germany; [2]Technical University of Munich; Yiwen.Zhu@bauhaus-luftfahrt.net

In line with the goals of the Paris Agreement, airlines are committed to achieving net-zero carbon emissions by 2050. To help achieve this goal, we assess the potential for reducing CO2 emissions when aircraft are shared, passengers are bundled, and flight networks are restructured across airlines, comparing the status quo with optimized networks in both current and future scenarios. We develop a mixed-integer program to determine how many flights should be operated between any two pairs of airports and which aircraft type(s) should be used on each route to minimize overall CO2 emissions. We consider aircraft performance characteristics, airport capacity, the compatibility of aircraft type assignments to routes, the continuous flow of aircraft between airports, and demand satisfaction. Passengers may have up to two stops between their origin and destination. To solve the problem efficiently, we propose an approach based on column generation. For our analyses we use real data for the European, North American and Transatlantic markets.

Scheduling Inductive Charged Passenger Buses on Airport Aprons

Niklas Pöch

Leibniz University Hannover, Germany; niklas.poech@prod.uni-hannover.de

Given the increasing importance of sustainability in the aviation sector due to climate change, electrifying ground vehicles on airport aprons is one way to reduce emissions. Dynamic inductive charging, which wirelessly charges vehicles while moving, is especially suitable for airport apron vehicles as it eliminates downtime for charging electric vehicles compared to conductive charging. We focus on scheduling electric passenger buses on airport aprons that use an inductive charging infrastructure to charge their batteries. Specifically, we investigate which vehicle should perform each service trip, whether it is transporting passengers from a gate to an airplane or from an airplane to a gate. We aim to ensure the reliable operation of these buses and avoid delays and breakdowns due to empty batteries. We present a formulation of the problem using a mathematical model. With this model, we want to evaluate different inductive charging infrastructures.

A Liquid Hydrogen Aircraft Refuelling Problem

Jörn Serrer

University of Hanover, Germany; joern.serrer@prod.uni-hannover.de

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. In addition to 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. In a 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.

WC 22: Mobility and Electric Vehicles

Time: Wednesday, 04/Sept/2024: 1:00pm - 2:30pm · *Location:* Nordgebäude ZG 1080
Session Chair: Stefan Schwerdfeger

Dynamic programming for scheduling daily activities

Fabian Alejandro Torres, **Michel Bierlaire**
EPFL, Switzerland; fabian.torres@epfl.ch

To model the mobility of people in a city, it is necessary to construct realistic schedules for individuals that consider the constraints that they have when planning their daily schedules. This study introduces a dynamic programming framework to generate optimal schedules of daily activities in an activity-based model. We model the daily activity choices of individuals as a resource constrained shortest path problem, where individuals try to maximize the combined utility of the set of activities completed in a day. Activities belong to groups of mutually exclusive activities (e.g., leisure, education, work, lunch) where at most one activity in the group is completed. Every activity has a utility; however, the location of activities makes it expensive and time consuming to travel from one activity to the next. Time windows for each activity and other realistic constraints are considered. We apply dynamic programming to solve this problem and use decremental state space relaxations (DSSR) to gradually eliminate infeasible cycles between mutually exclusive activities. Our results show that it is feasible to find the optimal schedule quickly (i.e., in less than a second per individual) showing the potential to apply our framework to populations with millions of inhabitants.

Optimizing EV Charging Station Placement Under Grid Connection Uncertainties: A Stochastic Programming Approach

Gen Li[1], **Dominik Husarek**[2], **Domenico Tomaselli**[2], **Michel Ulbrich**[1]
[1]Technische Universität München, Germany; [2]Siemens AG, Germany; ge75pax@mytum.de

The rapid expansion of the electric vehicle (EV) market necessitates growth in public charging infrastructure. Yet, this growth is hampered by significant uncertainties in planning and operational costs, primarily due to variable grid connection expenses. These costs, influenced by local distribution system operators (DSOs), are often unpredictable and costly to calculate. Such uncertainties pose considerable challenges for Charging Station Operators (CSOs) in their strategic decision-making. Our study introduces a novel Multi-period Mixed-integer Stochastic Programming (MPSP) framework to manage these uncertainties and identify economically viable sites for new charging stations.

The MPSP framework introduces an enhanced charging capacity estimation method integrating EV arrival frequencies, parking durations, and active charging sessions to provide insights into station utilization rates and aid optimal CS placement. MPSP addresses grid connection and peak load operation costs across three periods: normal, peak, and night. It integrates an advanced scenario generation algorithm to simulate grid connection scenarios and facilitate Sample Average Approximation. A case study in a German town using synthetic grid data is conducted to validate MPSP. This study involved 158 points of interest, 12 candidate CS planning locations, and 15 substations for grid connections. Findings reveal that planning with complete grid data could enhance profitability by up to 50% compared to planning under uncertain grid connections, emphasizing the need for robust partnerships between CSOs and DSOs.

Utilizing real location data and synthetic charging statistics, this study underscores the importance of comprehensive data integration and collaborative planning, paving the way for cost-effective and grid-compatible EV infrastructure development.

Optimizing the electrification of roads with charge-while-drive technology

Stefan Schwerdfeger
Friedrich-Schiller-Universität Jena, Germany; stefan.schwerdfeger@uni-jena.de

Electrifying road-based long-haul transportation is an intricate task. Given the current state of battery technology, either the driving ranges of electric commercial vehicles (ECVs) are too short or high-capacity batteries are costly and so heavy that payloads are limited. An old, yet recently revitalized, charging infrastructure currently evaluated on multiple test tracks around the globe alternatively suggests charging of electric trucks while driving. Analogously to trams, trolley buses, or trains, ECVs are powered by an electric motor connected to overhead wires via a movable contact arm and supported by a battery or an extra conventional drive, which steps in on non-electrified road segments. In this presentation, we will first examine the strategic question of minimizing the installation costs for electrified highway kilometers while still providing sufficient energy for a given set of representative tours of electric vehicles. Afterwards, the second part of the presentation is dedicated to the operational planning task of how to route a single ECV executing full-truckload point-to-point deliveries along a highway main line where charge-while-drive infrastructure is fixedly installed along some but not all parts of the road.

WC 23: Scheduling in Transportation 1

Time: Wednesday, 04/Sept/2024: 1:00pm - 2:30pm · *Location:* Nordgebäude ZG 1090
Session Chair: Frank Wiedra

Spatial analysis of urban transportation networks

Barbara Himstedt, Frank Meisel
Kiel University, Germany; barbara.himstedt@bwl.uni-kiel.de

When optimizing transportation logistics through routing models, Euclidean distances are typically employed to test them and derive practical recommendations. However, transportation networks have varying topologies, especially in different urban environments. This leads to a discrepancy between Euclidean and actual distances, which poses a challenge to the applicability of these models in real-world scenarios. Spatial metrics could play a crucial role in bridging this gap between theoretical models and practical applications, as they help to understand the structures of transportation networks. They analyze the connections between different locations, provide information about the layout of roads, identify bottlenecks, and detect barriers. In this talk, we want to explore the relationship between certain spatial metrics and network efficiency in the context of routing problems. Specifically, pedestrian, bicycle, and road networks in different urban areas will be examined. First findings indicate that the approximation quality of Euclidean distances relies on the type of network and the size of the considered area. As expected, for localized trips, bicycle and pedestrian routes are more efficient than motorized traffic routing. However, there are exceptions, and the advantage of non-motorized vehicles varies depending on the characteristics of the network. It therefore seems useful to consider the urban structure before applying general results to practice.

A Line-based Primal Heuristic for Periodic Timetabling

Patricia Ebert[1], Berenike Masing[1], Niels Lindner[1], Ambros Gleixner[1,2]
[1]Zuse Institut Berlin, Germany; [2]Hochschule für Technik und Wirtschaft Berlin, Germany; ebert@zib.de

As periodic timetables are used in public transport in many European countries, and in some cases also in freight transport, their construction, and optimization are inevitable tasks. We use the periodic event scheduling problem (PESP), first introduced by Serafini and Ukovich, as our underlying mathematical model. That PESP instances are generally notoriously hard to solve not only in theory but also in practice can be seen as none of the 16 instances of the benchmark library PESPlib could be solved to proven optimality so far. Therefore, focusing on the primal bound, we present a line-based primal heuristic in which we build an instance line by line. For this purpose, we define and analyze measures for the importance of a public transport line. Starting with the most important one, we optimize this subinstance and successively add further lines by decreasing order of importance. We propose a method to extend the solution of the previous iteration to the next to obtain a feasible starting solution by constructing a feasible periodic potential in a directed spanning tree and utilizing the instance structure. We then use the black-box solver ConcurrentPESP to optimize the solution for a fixed amount of time. Hereby, the starting solution is not fixed in the optimization step, so that previous decisions can be revised. In our computational experiments, the heuristic found better primal bounds for two out of the four tested PESPlib-instances. An improvement of 2.3 % was achieved for one instance.

Combining Simulation, Machine Learning and Heuristics for Solving Routing Problems

Mohammad Peyman[1], Xabier A.Martin[1], Javier Panadero[2], Angel A.Juan[1]
[1]Universitat Politecnica de Valencia, Spain; [2]Universitat Autònoma de Barcelona; mpeyman@upv.es

In this work, we present a novel sim-learnheuristic approach to solving the Team Orienteering Problem (TOP), departing from the traditional focus on deterministic and stochastic variants of the task. By combining deterministic, stochastic, and dynamic features in a hybrid manner, our methodology presents a novel use of the sim-learnheuristic algorithm to address the complex problems of the TOP. Essentially, TOP is about distributing tasks and routing as efficiently as possible for a team while taking into consideration dynamic variables like weather, traffic, and resource variations. This task becomes much more complicated when stochastic travel times and dynamically changing factors are added. Our approach effectively navigates the dynamic travel times, forecasts future situations, and finds the best solutions by combining machine learning predictions, heuristic algorithms, and simulation-based optimization.

Multi-mode personnel scheduling in Roll-on/Roll-off terminals

Frank Wiedra
Helmut Schmidt University/University of the German Federal Armed Forces; frank.wiedra@hsu-hh.de

In Roll-on/Roll-off (RoRo) terminals, the maritime transshipment of vehicles is performed as a pre- and post-processing for maritime transportation with RoRo ships, collectively referred to as RoRo operations. RoRo operations are an important part of the vehicle distribution in automotive supply chains, and during loading and unloading, vehicles roll on and off a ramp to be stowed on the decks of the RoRo ship or stored in the parking areas of the RoRo terminal. In this context, the field of Operations Research offers the potential to address increasing operational costs and throughputs by supporting efficient and effective personnel scheduling. Since loadings mirror unloadings in reverse order, we focus on loadings for simplicity and consider personnel performing different operational tasks, such as personnel who drive vehicles from the parking areas to the decks, or personnel who drive shuttles to bring personnel from the decks back to the parking areas. Groups of vehicles stored in the parking areas and planned for loading are called batches. We consider the specific problem where there is a determined departure of the RoRo ship and there is a shortage of personnel in the RoRo terminal, so it is not possible to load all the batches as planned. We formalize this as multi-mode personnel scheduling and use a weighting for each batch to decide whether to load or not in order to maximize the sum of weightings of the loaded batches.

WD 01: Semiplenary Kaminsky

Time: Wednesday, 04/Sept/2024: 3:00pm - 4:00pm · *Location:* Audimax
Session Chair: Margaretha Gansterer

Freight Capacity Portfolio Design in a Two-Sided Freight Marketplace

Phil Kaminsky

Amazon, United States of America; kaminsky@berkeley.edu

In the Amazon linehaul transportation marketplace, Amazon acquires capacity to ship truckloads in its middle mile network, and provides capacity to external shippers. Because of Amazon's high shipment volumes and commitment to rapid delivery of goods to customers, some capacity is most efficiently acquired long before it is utilized, while some capacity is best acquired immediately preceding its use. Amazon's large internal demand for linehaul shipping means that Amazon is well-positioned to do this, acquiring a portion of capacity through medium and long-term contracts before specific demand for that capacity is identified, while delaying the acquisition of dynamically priced spot capacity for highly uncertain demand. At Amazon, we have developed a transportation marketplace, and a series of models and tools, that allow Amazon to use pricing levers to optimize its transportation capacity portfolio. This approach enables Amazon to effectively align capacity risk, supply risk and price, and to provide carriers and shippers with tools to effectively manage their operations. We give an overview of this marketplace and survey some of the models that we have built to balance and price our capacity portfolio.

Joint work with: Idil Arsik, Timothy Jacobs, Goutam Kumar, Roger Lederman, Priyanka Mhatre, Mohsen Moarefdoost, Jacob Tutmaher

WD 02: Semiplenary Parmentier

Time: Wednesday, 04/Sept/2024: 3:00pm - 4:00pm · *Location:* Theresianum 0602
Session Chair: Maximilian Schiffer

Recent Trends in Combinatorial Optimization Augmented Machine Learning

Axel Parmentier

Ecole des Ponts Paristech, France; axel.parmentier@enpc.fr

Combinatorial optimization augmented machine learning (COAML) is a novel and rapidly growing field that integrates methods from machine learning and operations research to tackle data-driven problems that involve both uncertainty and combinatorics. These problems arise frequently in industrial processes, where firms seek to leverage large and noisy data sets to better optimize their operations. COAML typically involves embedding combinatorial optimization layers into neural networks and training them with decision-aware learning techniques. This talk provides an overview of the field, covering its main applications, algorithms, and theoretical foundations. We also demonstrate the effectiveness of COAML on contextual and dynamic stochastic optimization problems, as evidenced by its winning performance on the 2022 EURO-NeurIPS challenge on dynamic vehicle routing.

WD 03: Semiplenary Tan

Time: Wednesday, 04/Sept/2024: 3:00pm - 4:00pm · *Location:* Theresianum 0606
Session Chair: Martin Grunow

Collaborate for Good: Orchestrating Sustainability in Supply Chains

Tarkan Tan

University of Zürich, Switzerland; tarkan.tan@business.uzh.ch

Firms are under increasing pressure from their stakeholders to adopt sustainability measures for the goods or services they produce. However, the risks and opportunities associated with sustainability go beyond a firm's own operations and extend to their supply chain partners. In this talk, we will explore ways in which firms can enhance sustainability in their supply chains through collaboration.

WE 02: Metaparameter-Sensitivity, Heuristics and Data Integration in Machine Learning

Time: Wednesday, 04/Sept/2024: 4:30pm - 6:00pm · *Location:* Theresianum 0602
Session Chair: Sven F. Crone

Beyond Instinct: Exploring Revenue Forecasting with Heuristics and Machine Learning

Florian Artinger[1], Nikita Kozodoi[2], Julian Runge[3]
[1]Berlin International University of Applied Sciences, Germany; [2]Amazon Web Services; [3]Northeastern University; artinger@berlin-international.de

People’s predictions based on first impressions, also referred to as predictions from thin slices of data, can be surprisingly accurate. Investigating revenue predictions from thin slices, we analyze a simple expert algorithm, the “multiplier heuristic,” whereby revenues in the first t days are multiplied by a constant. Is there necessarily a trade-off between simplicity and predictive accuracy? Building on the bias–variance decomposition, we develop three conditions under which such a simple heuristic can match or even outperform more complex algorithmic prediction models. On 20 data sets, including 5 from the tech industry where the multiplier heuristic was originally applied, we show that a small sample size and a long observation duration provide performance advantages for the heuristic. Yet, given unpredictable changes over time, which can be characteristic of the tech industry, even a large sample size and a short observation duration may not yield any performance advantage for more complex algorithmic prediction models.

Integrating Large Citation Data Sets for Measuring Article’s Scientific Prestige

Inci Yueksel-Erguen, Ida Litzel
Zuse Institute Berlin, Germany; yueksel-erguen@zib.de

Evaluating scientific impact necessitates precise measurement of individual articles' impact, which is commonly assessed through metrics reliant on citation counts. However, these metrics are subject to limitations, notably susceptibility to manipulation within the scholarly community. Recently, there has been a shift towards utilizing knowledge distilled from citation graphs rather than relying solely on citation counts. This shift mandates access to a comprehensive citation graph for more reliable measurement.

In this study, we focus on methods for merging citation data sets incorporating big data to construct a comprehensive citation graph. We present our implementation results for merging two extensive citation databases, containing more than 63 million and 98 million article records, respectively, alongside more than 953 million and 1.3 billion citations. During our implementation, handling big data presented significant challenges, including quality issues that stemmed from semi-structured data lacking universal identification numbers. Through meticulous deduplication efforts, we streamlined the merged database to a single consistent dataset. Our work led to a citation graph that portrays inter-article associations more accurately than graphs derived from single databases.

The presentation outlines our approach to managing big data for constructing the merged citation graph, emphasizing the challenges and our remedies to deal with these challenges.

Sensitivity of Artificial Neural Networks for Metaparameters - an Empirical Evaluation on Sparse Data

Sven F. Crone
iqast & Lancaster University, United Kingdom; s.crone@iqast.de

The success of Deep Neural Networks for pattern recognition in speech, image and text data promises preeminent accuracy in time series patterns for forecasting. However, a recent survey and consultancy reports indicate that over 50% of all AI forecasting projects with Deep Networks in industry fail. In an attempt to reconcile this discrepancy, we run a large scale empirical study to assess the empirical accuracy of different deep and shallow neural networks architectures on a real world industry dataset from a FMCG manufacturer, using reliable error metrics, fixed multi-step horizons and multiple rolling time origins. Our experiments indicate that the standard implementations of both deep and shallow neural networks architectures - as well as recent data science methods including Facebook’s Prophet, Google’s bsts and machine learning methods such as XGBoost, and random forests, fail to outperform established statistical benchmarks of Exponential Smoothing and ARIMA on monthly industry data. A careful review of the methods' setup in standard packages in R suggests the use of inferior meta-parameters and flawed methodologies, which limit the accuracy of these "vanilla" implementations. To remedy their shortcomings, we tune the meta-parameters of selected algorithms and assess the sensitivity of these advanced methods to poor initial standard-meta-parameters in R and Python. As a result, we showcase how improved meta-parameters as well as carefully engineered feature creation, feature transformation and feature selection can significantly increase the accuracy and / or speed of both shallow and deep neural network architectures in industry practice leading to successfull implementations.

WE 03: Forecasting

Time: Wednesday, 04/Sept/2024: 4:30pm - 6:00pm · *Location:* Theresianum 0606
Session Chair: Robin Reiners

Extended SPEC: Analysing Loss Functions for Forecasting Sparse Time Series

Joshua Arnold, Maximilian Moll, Stefan Pickl

University of the Bundeswehr Munich, Germany; joshua.arnold@unibw.de

Time series forecasting has gained significant interest in recent years, not lastly due to its practical applicability in the form of demand forecasting in the field of logistics and e-commerce. Current methods frequently suffer from poor performance when applied to time series that exhibit a high degree of sparsity. However, in practice time series representing demands of goods in a warehouse for instance are highly sparse, with frequent time steps associated with zero demand. In literature, this problem is commonly referred to as Intermittent Demand Forecasting (IDF). In this paper, we will focus on one of the problems that arise in the context of IDF, namely that traditional time series loss functions are not well suited for the intermittent demand forecasting problem. Within this work, we will focus on identifying and resolving a number of shortcomings of an existing loss that has been specifically designed for IDF. Namely, Stock-keeping-oriented Prediction Error Costs (SPEC). We identify and propose solutions to a range of issues in aforementioned loss definition. We evaluate our method empirically by training models with our enhanced loss function on openly accessible benchmark datasets.

Improving machine learning based time series forecasts: The relevance of short-run information for daily financial forecasts

Theo Berger

Hochschule Hannover, Germany; theo.berger@hs-hannover.de

In this paper, we present a novel perspective on data filtering and present an innovative wavelet-based approach that leads to improved ML based time series forecasts. A separation of financial time series components into short-, mid- and long-run components allows us to study the relevance of these frequency components with respect to a statistical accuracy assessment for daily return forecasts. A simulation study and an analysis of daily market prices suggest that particular short- and midrun information components cover the relevant information that is necessary for estimating precise daily forecasts. Furthermore, the deconstruction of a time series into different frequency components in combination with Machine Learning results in superior forecasting performance in comparison to econometric benchmarks.

Multi-variate Density Estimation of Lead Time Demand

Robin Reiners, Florian Sachs, Ulrich Thonemann

University of Cologne, Germany; robin.reiners@uni-koeln.de

The cumulative distribution function (CDF) of lead time demand stands at the heart of any inventory control application. Historically, the inventory control literature has concentrated on deriving theoretical distributions for lead-time demand and forecasting demand. Recent shifts in the literature advocate for a direct estimation of lead-time demand, either through estimating empirical distributions by the means of bootstrapping or by forecasting it directly (Babai et al. 2022, Boylan and Babai 2022). This research seeks to empirically assess these emerging methodologies, particularly in the challenging landscape of spare parts where both demands and lead times are sporadically observed. Moreover, we probe into the potential of machine learning, motivated by Bertsimas and Kallus (2020), as a tool to enhance the estimation of the CDF of lead-time demand, especially in scenarios with limited observational data.

We explore nonparametric conditional density estimation (CDE) tools (Bertsimas and Kallus 2020, Dalmasso et al. 2020). We posit that this density-centric approach provides a more detailed representation of the uncertainties surrounding lead-time demand within the spare parts context. We compare this approach against recently proposed bootstrapping and direct forecasting methods using real-world data, addressing the challenges associated with intermittent lead time observations.

This study bridges the classical paradigms focused on theoretical lead-time demand distributions and the emergent emphasis on its direct empirical estimation. Furthermore, by employing machine learning techniques, we want to develop a novel approach for estimating the CDF of lead-time demand, addressing the challenges faced in a spare parts inventory context with limited observational data.

WE 04: Logistics and Transportation under Uncertainty

Time: Wednesday, 04/Sept/2024: 4:30pm - 6:00pm · *Location:* Wienandsbau 2999
Session Chair: Andreas Hagn

Uncertainty Mitigation in Berth Allocation Planning

Lorenz Kolley, Kathrin Fischer
Hamburg University of Technology, Germany; lorenz.kolley@tuhh.de

The aim of berth allocation planning is to derive conflict-free vessel assignments to the quay of a container terminal. The berthing schedule resulting from solving the corresponding Berth Allocation Problem (BAP) consists of the berthing times and positions of all vessels that are expected to arrive within a certain timeframe; these vessels are scheduled according to their respective arrival and handling times. However, both these times are uncertain due to different influences, e.g., weather, technical breakdowns or maintenance.

Deviations from the planned arrival and handling time lead to delayed vessel departures, which cause waiting time for the succeeding vessels and can ultimately result in conflicts that may impede the schedules' feasibility. Hence, updating or re-planning of berthing schedules can become necessary, but this is costly and may be impossible when a plan is already under execution. Therefore, the aim of this work is to derive robust berthing schedules which are resistant to uncertainties, especially of handling times, by applying time buffers.

Two main strategies can be distinguished regarding the development and use of time buffers for mitigating these uncertainties: Maximizing the slack (buffer) between each pair of succeeding vessels or considering a predetermined individual time buffer in the optimization of the berthing schedule. The results of both approaches are evaluated in this work from an ex-post perspective using real vessel AIS data, i.e., the actual arrival and handling times of vessels approaching an existing port.

Adjustable Robust Optimization for Transport Planning with Uncertain Demands

Eranda Cela[2], Sabina Kiss[1,2], Bettina Klinz[2], Stefan Lendl[1]
[1]S2data GmbH, Austria; [2]Graz University of Technology, Austria; sabina.kiss@s2-data.at

Uncertainty in demands is a pervasive issue in manufacturing and logistics.

The implementation of just-in-time approaches and minimal inventory management has led to significant difficulties in the supply chain, particularly in the planning of transportation of goods. This has resulted in avoidable transports, which have caused unnecessary costs and greenhouse gas emissions. When some of the input data is uncertain, robust optimization is a method to model these uncertainties and find efficient solutions.

It is well-known that applying classic robust optimization techniques may result in overly conservative decisions, which may not always be the best course of action in real-world applications. Adjustable robust optimization (ARO) relaxes this notion by introducing a second stage, where some of the decisions can be made after the uncertain data is known. The use of ARO achieves better results compared to the application of classic robust optimization.

We develop an ARO model for a transportation problem where the demands for materials to be transported from a source to a sink are uncertain. All necessary physical constraints are taken into account, including maximum vehicle load and 3D cargo bay packing. For the demand uncertainty, different uncertainty sets are applied, and methods are investigated to estimate the parameters for these uncertainty sets.

In practise, this model and budgeted cumulative uncertainty sets are used to develop a heuristic solution approach for the problem. This resulting approach uses meta-heuristics like simulated annealing and genetic algorithms. We evaluate its performance on both random generated data and real-world data.

A Branch-Price-Cut-And-Switch Approach for Optimizing Team Formation and Routing for Airport Baggage Handling Tasks with Stochastic Travel Times

Andreas Hagn, Rainer Kolisch, Giacomo Dall'Olio, Stefan Weltge
Technical University of Munich, Germany; andreas.hagn@tum.de

In airport operations, optimally using dedicated personnel for baggage handling tasks plays a crucial role in the design of resource-efficient processes. Teams of workers with different qualifications must be formed and baggage tasks must be assigned to them. Each task has a time window within which it can be started and should be finished. Violating these temporal restrictions incurs severe financial penalties for the operator. In practice, various components of this process are subject to uncertainties. We consider the aforementioned problem under the assumption of stochastic travel times across the apron. We present two binary program formulations to model the problem at hand and solve it with a Branch-Price-Cut-and-Switch approach, in which we dynamically switch between two master problem formulations. Furthermore, we use an exact separation method to identify violated rank-1 Chvátal-Gomory cuts and introduce an efficient branching rule. We test the algorithm on instances generated based on real-world data from a major European hub airport. Our results indicate that our algorithm is able to significantly outperform existing solution approaches. Moreover, an explicit consideration of stochastic travel times allows for solutions that utilize the available workforce more efficiently, while simultaneously guaranteeing a stable service level for the baggage handling operator.

WE 05: Methods for Robust and Stochastic Optimization 2

Time: Wednesday, 04/Sept/2024: 4:30pm - 6:00pm · *Location:* Wienandsbau 3999
Session Chair: Felix Engelhardt

On Norm-Based Approximation Algorithms for Robust Combinatorial Optimization

Werner Baak[1], Marc Goerigk[1], Adam Kasperski[2], Pawel Zielinski[2]

[1]University of Passau, Germany; [2]Wroclaw University of Science and Technology, Poland; marc.goerigk@uni-passau.de

For a min-max robust optimization problem with a discrete uncertainty set, a well-known heuristic is to optimize a nominal problem with the average-case scenario. If there uncertainty set contains K scenarios, this approach results in a K-approximate solution. It is equivalent to optimizing the 1-norm of the K-dimensional vector that contains the objective value in each scenario. If we use other p-norms, it is possible to achieve better guarantees that improve when the value of p increases. By using an approximation method for some such p-norm problems, it is possible to achieve approximation guarantees that are logarithmic in K. We also point out how to extend this approach to the more general OWA decision criterion with non-increasing weights, resulting in an approximation guarantee that is in O(log K / w_1) for matroidal problems.

On Two-Stage Robust Representative Selection Problems with Budgeted Uncertainty

Marc Goerigk[1], Dorothee Henke[1], Lasse Wulf[2]

[1]University of Passau, Germany; [2]Technical University of Denmark; dorothee.henke@uni-passau.de

A standard type of uncertainty set in robust optimization is budgeted uncertainty, where an interval of possible values for each parameter is given and the total deviation from their lower bounds is bounded. In the two-stage setting, discrete and continuous budgeted uncertainty have to be distinguished. While two-stage robust selection problems with discrete budgeted uncertainty have been shown to be NP-hard, the complexity of the corresponding problems with continuous budgeted uncertainty has still been open. Only for an alternative version of continuous budgeted uncertainty, where the total absolute deviation of all parameters is bounded instead of the sum of all relative deviations, the two-stage robust selection problem has been shown to be solvable in polynomial time. We close a gap in the knowledge about the complexity of these problems by showing that the two-stage robust representative selection problem with the more common version of continuous budgeted uncertainty is solvable in polynomial time. After applying standard dualization techniques to reformulate the problem as a mixed-integer linear program, we present a combinatorial algorithm to solve the latter.

Submodular Cuts in Budgeted Robust Optimisation under Objective Uncertainty

Christina Büsing, Felix Engelhardt, Timo Gersing

RWTH Aachen, Germany; engelhardt@combi.rwth-aachen.de

Consider a binary integer program (BIP) under budgeted objective uncertainty, i.e. the cost of a given number of objective coefficients may deviate within an interval.

The objective of such a BIP consists of a linear nominal and a non-linear robust part. The robust part can be restated as a submodular set function, where the set corresponds to the non-zero solution variables. This set function defines a polymatroid Π.

Using results by Bertsimas and Sim, the BIP can also be reformulated into a mixed integer linear program, with a linear objective function that again consists of a robust and a nominal part.

The nominal parts of the objective functions are identical. Comparing the robust part of the objective functions, it can be shown that the linear robust objective function part is larger than any solution vector x multiplied with a coefficient vector π from the polymatroid Π. Thus, we can derive valid inequalities for any (fractional) solution vector x. The strongest such inequalities are those that maximise πx. Since Π is a polymatroid, we can greedily compute a coefficient vector π from the polymatroid Π that maximises πx using results from Joung and Park (2021), based on work from Edmonds.

In practice, we only need to consider those constraints on the polymatroid that correspond to feasible solutions of the original binary integer program. In this talk, we present ongoing research on to what extent this can be included in the polymatroid optimisation problem to speed computations by strengthening the valid inequalities.

WE 06: Facility Layout, Betweenness, and Quadratic Linear Ordering

Time: Wednesday, 04/Sept/2024: 4:30pm - 6:00pm · *Location:* Wirtschaftswissenschaften Z534
Session Chair: Sven Mallach

The undirected circular facility layout problem

Louisa Schroeder, Anja Fischer

TU Dortmund University, Germany; louisa.schroeder@tu-dortmund.de

In the directed circular facility layout problem (DCFLP) one has given a set of departments, their lengths and pairwise weights between the departments. In contrast to the single row facility layout problem (SRFLP), where departments are arranged along one side of a path without overlapping, the DCFLP looks for an arrangement on a circle such that the sum of the weighted center-to-center distances measured in clockwise direction is minimized.

In this talk, we present a new facility layout problem, the undirected circular facility layout problem (UDCFLP). For each pair of departments we consider here the shortest distance along the circle, either travelling in clockwise or in counter-clockwise direction.

We present two new mixed-integer linear programming models for the UDCFLP, whereby one model is an adaptation of a well-known model for the DCFLP and the other model is based on the well-known betweenness model for the SRFLP. We develop symmetry-breaking constraints and study the structure of the associated polytopes. Our models, which are strengthened by our new cutting planes, allow us to solve instances with up to 13 departments to optimality within a time limit of one hour. For larger instances we derive strong lower bounds exploiting the connections to some parallel machine scheduling problem.

The constrained single-row facility layout problem

Anja Fischer[1], Frank Fischer[2]

[1]TU Dortmund University, Germany; [2]Johannes Gutenberg University Mainz, Germany; anja2.fischer@tu-dortmund.de

Given a set of departments, their lengths and pairwise weights the single-row facility layout problem (SRFLP) asks for an arrangement of the departments along one side of a path such that the weighted sum of the center-to-center distances is minimized. In the constrained SRFLP certain ordering and positioning conditions have to be satisfied. We present some new constraints for strengthening the betweenness approach presented by Maier and Taferner. Optimal solutions or strong lower bounds are derived using a cutting plane approach where the linear programs are solved using an interior point method.

Apart from this we show that the so called weighted linear ordering problem, which leads to asymmetric betweenness variables, can be handled as well by our approach by a transformation to the standard betweenness model. This allows us to solve some previously unsolved instances rather fast.

Betweenness and Quadratic Linear Ordering - Asymmetric Models and Structural Relations

Sven Mallach

University of Siegen, Germany; sven.mallach@cs.uni-bonn.de

We present novel binary linear programs to model betweenness relations, and reveal favorable structural results as well as handy relations to the (linearized) quadratic linear ordering problem. The findings can be exploited to obtain compact and strong relaxations for dense as well as sparse application settings.

WE 07: Non-linear Multi-(level or criteria) Discrete Optimization

Time: Wednesday, 04/Sept/2024: 4:30pm - 6:00pm · *Location:* Wirtschaftswissenschaften Z536
Session Chair: Elisabeth Gaar

Leveraging Semi-Definite Programming for Multi-Objective Single-Row Facility Layout Problems

Arezoo Amiri[1], Christof Brandstetter[1], Elisabeth Gaar[2], Sophie Parragh[1], Markus Sinnl[1]
[1]Johannes Kepler University Linz, Austria; [2]Universtiy of Augsburg, Germany; christof.brandstetter@jku.at

In the single-row facility layout problem (SRFLP), the goal is to arrange a set of facilities along a single line to minimize the sum of the weighted distance between facilities. The SRFLP is a well-known combinatorial optimization problem with many practical applications in industrial engineering, health care, office design, and other fields. In these fields, the SRFLP is often extended to a multi-objective optimization problem, where multiple conflicting objectives need to be considered simultaneously, such as the total material handling cost, flow distance or CO2 emissions.

For the single objective SRFLP semi-definite programs (SDP) have been proven to be a powerful tool to solve the problem. In this work, we propose a novel approach that leverages the power of SDP to solve the multi-objective SRFLP. In particular, we combine objective space techniques, such as the weighted sum method and the epsilon-constraint method with SPDs. We conduct a computational study to compare our approach with objective space methods using integer programming formulations on modified benchmark instances from

the literature.

On solving submodular interdiction games via branch-and-cut

Markus Sinnl[1], Kübra Taninmis[2]
[1]Institute of Business Analytics and Technology Transformation, Johannes Kepler University Linz, Austria; [2]Department of Industrial Engineering, Koc University, Istanbul, Turkey; markus.sinnl@jku.at

Many relevant applications from diverse areas such as marketing, wildlife conservation, and defending critical infrastructure can be modeled as interdiction games. In this talk, we consider interdiction games whose objective function is a monotone and submodular set function. Given a ground set of items, the follower seeks to maximize this function subject to knapsack constraints. Given an interdiction budget, the leader interdicts the usage of some of the items of the follower and the follower can only use the non-interdicted items in her maximization. The goal of the leader is to select the items to interdict in such a way that the objective value achievable by the follower is minimized. We present an exact branch-and-cut algorithm for this kind of interdiction game. The algorithm is based on interdiction cuts, which exploit the submodularity of the objective function and allow the leader to capture the follower's objective function value for a given interdiction decision of the leader. We also discuss extensions and liftings of these cuts and additional preprocessing procedures. We present a computational study on the weighted maximal covering interdiction game and the bipartite inference interdiction game.

Tackling a class of integer bilevel nonlinear programs with disjunctive cuts based on SOCP

Elisabeth Gaar[1], Jon Lee[2], Ivana Ljubić[3], Markus Sinnl[4], Kübra Tanınmış[5]
[1]University of Augsburg, Germany; [2]University of Michigan, Ann Arbor, Michigan, USA; [3]ESSEC Business School of Paris, France; [4]Institute of Business Analytics and Technology Transformation, Johannes Kepler University Linz, Austria; [5]Department of Industrial Engineering, Koc University, Istanbul, Turkey; elisabeth.gaar@uni-a.de

We study a class of integer bilevel programs with second-order cone constraints at the upper-level and a convex-quadratic objective function and linear constraints at the lower-level. We develop disjunctive cuts (DCs) to separate bilevel-infeasible solutions using a second-order-cone-based cut-generating procedure. Using these DCs, we propose a branch-and-cut algorithm for the problem class we study, and a cutting-plane method for the problem variant with only binary variables. A computational study demonstrates that both of our approaches outperform a state-of-the-art generic solver.

WE 08: Regularity in Continuous Optimization

Time: Wednesday, 04/Sept/2024: 4:30pm - 6:00pm · *Location:* Wirtschaftswissenschaften Z538
Session Chair: Oliver Stein

On the Computation of Second-Order Contingent Derivatives

Mario Jelitte

TU Dresden, Germany; mario.jelitte@tu-dresden.de

Formulas for the representation of the tangent cone to a given set are of fundamental importance in continuous optimization. It is well-understood that if the set of interest is described by smooth equalities and inequalities, then its tangent cone coincides with the linearization cone under appropriate constraint qualifications. One of these constraint qualifications is a Lipschitzian error bound condition. In some circumstances, however, the tangent cone is a proper subset of the linearization cone, and in these scenarios the Lipschitzian error bound condition is necessarily violated. For such cases, Ngai et al. showed, under a Hoelderian error bound condition, that the tangent cone can still be computed as the zero set of a higher-order contingent derivative. Until now, not much is known about these derivatives, and one of our goals is to work out some peculiarities that concern the chances for an easy computation of second-order contingent derivatives.

On calmness of the optimal value function in quasiconvex optimization

Diethard Klatte

University of Zurich, Switzerland; diethard.klatte@uzh.ch

In this talk, we present sufficient conditions for calmness from below and/or from above for the optimal value function v(.) of parametric optimization problems. We focus on perturbed models with quasiconvex objective and constraint functions, where the imposed conditions are also discussed with respect to special classes of problems. A main intention is to compare our study with classical results on lower and/or upper semicontinuity of v(.). In particular, we show for semi-infinite programs that v(.) is calm from below under quasiconvexity of the data and compactness of the solution set, which extends a standard theorem on lower semicontinuity of the optimal value function. Illustrative examples are given, which demonstrate the significance of the imposed assumptions even in the case of linear and quadratic programs. The contribution is based on the author's paper "On calmness of the optimal value function" published in Appl. Set-Valued Anal. Optim. 5 (2023), No. 2, pp. 253-264.

On the weakest constraint qualification for sharp local minimizers

Oliver Stein, Maximilian Volk

Karlsruhe Institute of Technology (KIT), Germany; stein@kit.edu

The sharp local minimality of feasible points of nonlinear optimization problems is known to possess a characterization by a strengthened version of the Karush-Kuhn-Tucker conditions, as long as the Mangasarian-Fromovitz constraint qualification holds. This strengthened condition is not easy to check algorithmically since it involves the topological interior of some set. In this paper we derive an algorithmically tractable version of this condition, called strong Karush-Kuhn-Tucker condition. We show that the Guignard constraint qualification is the weakest condition under which a feasible point is a strong Karush-Kuhn-Tucker point for every continuously differentiable objective function possessing the point as a sharp local minimizer. As an application, our results yield an algebraic characterization of strict local minimizers of linear programs with cardinality constraints.

WE 09: Pricing Applications

Time: Wednesday, 04/Sept/2024: 4:30pm - 6:00pm · *Location:* Wirtschaftswissenschaften Z532
Session Chair: Christiane Barz

Pricing Virtual Power Purchase Agreement by Monte Carlo Simulations

YuLi Tsai

Volue, Japan; yuli.tsai@volue.com

In this paper, we study the pricing structures of virtual power purchase agreement (Virtual PPA) by Monte Carlo Simulations. Virtual PPA is one of the most effective ways for corporates to engage the carbon emission reduction strategy. A virtual PPA is a contract for difference (CfD, i.e. a derivative contract) between power buyer and renewable energy generator which settle based on the difference between an agreed strike price and a quoted electricity wholesale price. Due to the variation of the electricity price in long-term period (i.e. 10 years to 20 years for virtual PPA contract), thousands of electricity price paths should be simulated by Monte Carlo methods to understand the risk structure of net present value from the viewpoints of power buyer and renewable energy generator based on a specific long-term electricity forward curve as a base scenario. A specific algorithm using Monte Carlo method is developed to estimate the volatility of the electricity price for future 20 years. The granularity of Japan Electric Power Exchange (JEPX) spot price is 30-minute. Several VPPA pricing structures with strike price scenarios including fixed-price nominal PPA, fixed with escalation (stepped), fixed with inflation indexation. The analysis results can provide concrete quantitative evidences for strike price negotiation between power buyer and renewable energy generator.

Pricing Strategies for 3D Printing-as-a-Service

Tarun Jain[1], Jishnu Hazra[1], Ram Gopal[2]

[1]Indian Institute of Management Bangalore; [2]Warwick Business School, The University of Warwick; tarun.jain@iimb.ac.in

The advent of 3D printing technology has facilitated new avenues for collaborative product design endeavors between manufacturers and consumers. The manufacturers now leverage the 3D Printing-as-a-Service (3DaaS) model by renting out 3D printers. In this paper, we study a game theoretic model setup and attempt to address the following research questions: What pricing model is suitable for offering 3DaaS? How do factors such as the degree of design customization and complexity impact the pricing strategy employed by the 3DaaS firm? Our findings indicate that when customers' influence on product quality is either high or low, the pay-per-build pricing model outperforms the fixed-fee pricing model. Additionally, we observe that in cases where customers frequently print intricate product designs, the firm may opt for the pay-per-build pricing model, contingent upon a low likelihood of design failure for these intricate structures.

Performing dynamic pricing for 1M industrial spare parts

Alwin Haensel, Tobias Kalinowski

Haensel AMS, Germany; alwin@haensel-ams.com

We will describe our pricing system setup for an US industrial spare part vendor. The objective is to maximize the profit by controlling the daily prices for approx. 1M products. Most products are niche products, e.g. 70% of the products sold in a given months, had no sale in the months before.

Our system uses the full web traffic and soft-conversion steps, to maximize the expected profit of a user. We developed the concept of 'conversion scores' to faster evaluate price tests at scale. In this talk we will explain the core system setup and the main challenges we faced in developing this pricing system.

Dynamic Pricing of Extra Seats under the Nested Logit Model

Christiane Barz[1], Jochen Gönsch[2], Davina Hartmann[2], Siqi He[1]

[1]University of Zurich, Switzerland; [2]University of Duisburg, Germany; christiane.barz@business.uzh.ch

We suggest a dynamic pricing model for selling "empty seats" -- seat reservations for extra space in addition to regular reservations. Such extra space tickets share the resources of the main product and are viewed as a significant revenue-generating opportunity when coaches, trains, or airplanes frequently depart with many empty seats.

We formulate the problem of a transportation company that sells tickets in the same compartment (1) without a seat reservation, (2) with a seat reservation, and (3) with a seat reservation and extra space as a Markov decision process (MDP). To address the resulting curse of dimensionality, we follow two approaches.

First, we state upper bounds based on a deterministic approximation and approximate linear programming (ALP). We show that under the Nested Logit demand model, the subproblem of the ALP row generation problem is tractable with an objective function that is convex in the action and linear in the components of the state. Corresponding decomposition approaches provide even tighter bounds. Second, we provide policies based on these bounds. To allow for more general basis functions, we also discuss a policy based on simulation-based approximate dynamic programming. An extensive numerical study shows that the approaches are competitive with general approaches from literature and the best approach is the simplified decomposition. It has an excellent revenue vs. run time trade-off, rendering it a clear first choice ready for application to real-world instances. We also quantify the extra revenue potential when offering extra seats, which is particularly large in low demand settings.

WE 10: Retail and Staffing

Time: Wednesday, 04/Sept/2024: 4:30pm - 6:00pm · *Location:* Wirtschaftswissenschaften 0514
Session Chair: Justus Arne Schwarz

"Analytical Framework for Reliability and Operational Dynamics of Retrial-based Repairable Systems"

George Mytalas, Dimitris Zisis
Aueb, Greece; mytalas@aueb.gr

We investigate the reliability and cycle analysis for a repairable k-out-of-n:G system with retrial of failed components. Such a model has important practical applications in fully automatic manufacturing system. Models for availability and reliability of the system whose components are all subject to two failure modes are presented.

One failure consists the specific component while there is the total failure-disaster-regarding all components. There is no waiting space for failed components in the system. If a failed component finds the repairman busy and it can not be repaired at once, it will enter into the retrial orbit and try again for repair after some random period of time. Some reliability indexes, including steady-state availability, reliability function and mean time to system first failure, are derived by using vector Markov process and Laplace transform theory. Also we explore the busy cycle and the idle system cycle providing useful results.

Staffing service systems with finite customer population and deadlines

Justus Arne Schwarz, Maximilian Kunz
University of Regensburg, Germany; justus.schwarz@ur.de

Service systems with a finite customer population occur if the maximum number of customers that can arrive is given, e.g., by the tickets that were sold for a flight. There is a trade-off between staffing costs and service quality, i.e., costs related to the waiting time and missing the deadline, e.g., the departure of the flight. From the service operator’s perspective, a key decision is to determine when and how many servers should be provided.

The literature on staffing decisions features constant and time-dependent staffing policies. For queueing systems with a finite customer population, state-dependent policies can exploit the information about the already served customers because it determines the number of customers left from the initial population and thereby the number of future arrivals. The literature encompasses state-dependent policies, where the number of servers can be changed depending on the already arrived, and severed customers. This requires a highly flexible workforce and flexible cost structures because the staffing depends on the realization of the arrival process.

We propose a new staffing policy that considers both servers scheduled according to a time-dependent policy and more expensive but flexible servers that follow a state-dependent policy. We formalize the optimization problem for queueing systems with a finite customer population for all discussed staffing policies. Solutions for the proposed staffing policy are generated by combining complete enumeration with stochastic dynamic programming. Numerical results that provide insights regarding the difference between the policies are presented.

WE 11: Human-AI Interface

Time: Wednesday, 04/Sept/2024: 4:30pm - 6:00pm · *Location:* Theresianum 2609
Session Chair: Andreas Fügener

How Prediction Intervals Improve Human Algorithm Collaboration

Chantale Köster, Cedric Lehmann, Andreas Fügener, Ulrich Thonemann
University of Cologne, Germany; chantale.koester@uni-koeln.de

For managerial decision tasks, humans and algorithms often work together with the intention to combine their skills and thereby achieve complementary performance, that is, a higher performance than either party could achieve on their own. Data from practice and research suggests that algorithmic advice often improves human decisions, however, not beyond the algorithmic performance. Missing collaboration mechanisms are seen as the main reason for unexploited complementary performance potential. A potential collaboration mechanism is to communicate algorithmic certainty.

In this paper, we analyze how human decision making in algorithmically supported tasks is affected by the provision of prediction intervals. In a laboratory experiment, participants worked on a forecasting task in which they and the algorithmic advisor had complementary skills and information. We show that prediction intervals are an effective collaboration mechanism causing a more appropriate reliance on advice. This way, decision makers rely more on accurate advice that comes with high certainty and less on inaccurate advice that comes with low certainty, leading to a higher complementary performance.

Our results contribute to a better understanding of how humans and algorithms can achieve complementary performance. We suggest that managers consider the provision of prediction intervals for algorithmically supported forecasting tasks, since they lead decision makers to efficiently use algorithmic advice and improve complementary performance.

Automation and Augmentation: Roles of AI in Collaborated Decision Making

Andreas Fügener, Dominik Walzner, Alok Gupta
Universität zu Köln, Germany; andreas.fuegener@uni-koeln.de

Artificial intelligence (AI) will have a growing influence in the future of work. Human decision-makers may see significant changes in their day-to-day work as collaboration between humans and AI will become commonplace. We explore the application of AI for automation (i.e., AI performing tasks independently) and for augmentation (i.e., AI advising humans) in collaborative environments. Using an analytical model, we show that whether AI should be used for automation or for augmentation depends on different types of human-AI complementarity: The share of automation increases with higher levels of between-task complementarity, which can arise due to task-level performance differences between humans and AI. In contrast, the share of augmentation increases with higher levels of within-task complementarity, which arise due to task-based interaction between humans and AI. We include both AI roles in a task allocation framework, where an AI and humans work on a set of classification tasks to optimize performance with a given level of available human resources. We validate our framework with an empirical study based on experimental data in which humans had to classify images with and without AI support. When between-task and within-task complementarity exist, we see an interesting distribution of work pattern for optimal work configuration: AI automates relatively easy tasks, augments humans on tasks with similar human and AI performance, and humans work without AI on relatively difficult tasks. Our work provides several contributions to theory and practice and our task allocation framework showcases potential job designs in the future of work.

WE 12: Applications in MCDM

Time: Wednesday, 04/Sept/2024: 4:30pm - 6:00pm · *Location:* Theresianum 2601
Session Chair: Mendy Tönsfeuerborn

Categorization of animal groups for the sustainable management of an livestock farm: using MCDM sorting method KEMIRA-Sort

Gilbert Tapsoba[2], Stéphane Aimé Metchebon Takougang[1], Désiré Ouedraogo[2]

[1]Université Aube Nouvelle, 06 B.P. 9283, Ouagadougou, Burkina Faso; [2]Université Joseph Ki-Zerbo, 03 B.P. 7021, Ouagadougou, Burkina Faso; metchebon@gmail.com

This work was carried out in order to identify the most advantageous species for sustainable management of an ex-situ breeding farm allowing animal visits. The structuring of the problem led us to identify the alternatives (wild animals) and their criteria evaluation. For this evaluation, in other to respect the heterogeneity of dimensions of the sustainability

and make easer the task of the stakeholders involved in the decision process (e.g. criteria weighting), we used the multiple criteria sorting method KEMIRA-sort. Using this method led to elicit the weight of each criterion and to identify a categorization of animal groups that could enable sustainable management of the ex - situ breeding farm of Wédbila in Burkina Faso (Western Africa). We obtained a result in line with empirically estimation of the principle stakeholder playing the role of Decision Maker. These results confirm the effectiveness of the KEMIRA-sort method and the flexibility of the proposed approach shows its ability to be applied in any other context of sustainable ex-situ livestock farm management.

Towards Inverse SMAA as a tool for assessing stakeholders' attitudes towards energy scenarios

Matthias Grajewski[1], Luis Hasenauer[1], Stefan Vögele[2]

[1]FH Aachen University of Applied Sciences, Germany; [2]Forschungszentrum Jülich, Institute of Energy and Climate Research-Jülich Systems Analysis (IEK-3); grajewski@fh-aachen.de

In a free society, any transformation that affects society as a whole must be supported by a significant fraction of the stakeholders involved in order to be successful in the long term. This applies in particular to the transformation of the energy system towards increased sustainability. Once a number of possible future scenarios have been identified, it is therefore necessary to determine the attitude of the stakeholders in order to be able to assess the acceptance of corresponding measures in advance. However, surveys are often time-consuming and expensive.

Applying stochastic MCDA methods such as SMAA can contribute to assess stakeholder attitudes towards hypothetical scenarios. In this approach, uncertainties in data as well as heterogeneities within stakeholders and social groups are systematically addressed. Our contribution is to systematically derive information on the attitudes of stakeholders from preferences observed today under existing uncertainties and to use this information alongside other sources of information to assess the acceptance of what-if scenarios by various stakeholders. This involves formulating and solving an inverse SMAA approach. Our method makes it possible for assessing hypothetical scenarios, if necessary, to dispense with intensive empirical work with stakeholders, but to incorporate such information if it is available. It moreover allows for assessing the robustness of the decision or preferences exploiting geometrical information depending on the underlying MCDA model, in our case Promethee II.

In our talk, we apply our method to the transition to different possible energy scenarios.

Value-oriented decision making: Weighting of personal values in career decisions

Mendy Tönsfeuerborn, Sarah Schiffer, Rüdiger von Nitzsch

RWTH Aachen University, Germany; toensfeuerborn@efi.rwth-aachen.de

Personal values are an overarching concept shaping people's motives and guiding their decisions and actions. Therefore, important life choices with far-reaching consequences should be considered and made in accordance with ones personal values. In this study, we examine to which extent the most highly prioritized personal values are reflected by the objectives used in the decision-making process and their weights. Determining the amount of objective weights related to the most prioritized personal values with data from real decision-making situations enables us to evaluate whether the resulting decisions of our subjects are actually in line with their personal values.

We analyze data from german students with the help of the Entscheidungsnavi, a free-to-use decision support system that guides a decision process based on the Value-Focused Thinking approach by Keeney. As part of the lecture 'decision theory ', the students were asked to systematically work out a complex decision that was important to them. The Entscheidungsnavi guided the students step by step through the process, starting with a reflection of their personal values. We compare two different settings: In the first setting, the five most prioritized values are automatically considered by the tool when defining the objectives. In the second setting, the decision maker has to define the objectives without this help.

WE 13: Optimization and AI

Time: Wednesday, 04/Sept/2024: 4:30pm - 6:00pm · *Location:* Theresianum 2605
Session Chair: Jens Schulz

AMPL: Advances in Python Integration, Cloud Deployment, and Generative AI

Filipe Brandão

AMPL Optimization, Inc., United States; fdabrandao@ampl.com

Python and its vast ecosystem are great for data pre-processing, solution analysis, and visualization, but Python's design as a general-purpose programming language makes it less than ideal for expressing the complex optimization problems typical of prescriptive analytics. AMPL is a declarative language that is designed for describing optimization problems and that integrates naturally with Python.

In this presentation, you'll learn how the combination of AMPL modeling with Python environments and tools has made optimization software more natural to use, faster to run, and easier to integrate with enterprise systems. We will show how AMPL and Python work together in a range of contexts:

- Installing AMPL and solvers as Python packages anywhere
- Fast data transfer from/to Python data structures such as Pandas and Polars dataframes
- Deploying models to the cloud quickly and easily

You'll also see how generative AI technology is enabling a rapid development process for both AMPL and Python, reducing the time and effort to produce a working application that's ready for end-users.

Leveraging Trained ML Models within Optimization Models

Kostja Siefen

Gurobi Optimization; siefen@gurobi.com

Machine learning has become a prevalent tool for providing predictive models in many applications. We are interested in using such predictors to model relationships between variables of an optimization model in Gurobi. The Gurobi Machine Learning Python package makes it easy to insert regression models trained by popular frameworks (e.g., scikit-learn, Keras, PyTorch, XGBoost, LightGBM) directly into an optimization model. These regression models may be linear or logistic regressions, neural networks, or based on decision trees. In this talk, we will present the functionalities and applications of Gurobi Machine Learning and demonstrate best practice applications.

Generative AI in Decision Support Tools

Jens Schulz

FICO, Germany; schulz_jens@gmx.net

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, and it shows promising research areas for leveraging GenAI in the field of Operations Research: code generation to increase productivity, chatbots for documentation, generation of mathematical optimization models - just to name a few. In this talk we present an experiment which combines LLMs and decision support tools for decision making in FICO Xpress Insight, e.g. to create an optimized pricing strategy.

Large language models (LLMs) frequently produce incorrect or misleading results, a phenomenon commonly called "hallucination". We demonstrate basic examples where a slight adaptation of a question (prompt) turns a previously helpful LLM response into a false statement. Besides such observations of inaccuracies, we need to consider data exposure, data leakage, privacy violations, copyright violations, biased answers, dangerous or unethical usage, inappropriate language and malicious code, and discuss answers to these challenges. Best practices need to be followed to responsibly leverage GenAI in decision support tools!

It is important to balance innovation with risk mitigation when leveraging GenAI for decision-making, and we advocate for a holistic approach that combines technological advancements with ethical considerations and human oversight.

WE 14: Decision Support and Heuristics

Time: Wednesday, 04/Sept/2024: 4:30pm - 6:00pm · *Location:* Theresianum 2607
Session Chair: Diana HweiAn Tsai

A model-driven decision support system for multi-level lot-sizing problems of pharmaceutical tablets manufacturing systems

Michael Simonis, **Stefan Nickel**

Karlsruhe Institute of Technology, Germany; michael.simonis@partner.kit.edu

This paper discusses a decision support system (DSS) for the multi-level capacitated lot-sizing problem with linked lot sizes, backorders, and integrated shelf-life rules (MLCLSP-L-B-SL) applied to a pharmaceutical tablets manufacturing process. An exact mathematical formulation of the MLCLSP-L-B-SL is introduced. A Pareto analysis balancing costs, reliability of deliveries, and shelf-life requirements is outlined. Moreover, the developed DSS, its user interface, data management, and an optimization system are described. Outcomes of numerical experiments with real-world pharmaceutical tablets manufacturing processes are evaluated in terms of costs, service-level metrics, and expired inventories. Finally, planning rules and managerial insights are given for lot-sizing under shelf-life constraints.

Dynamic Order Assignment Methods to Affiliated Stores Using Voronoi Tessellation

Takaki Kawamoto, **Takashi Hasuike**

Waseda University, Japan; taka1023@suou.waseda.jp

Recently, specific e-commerce site management companies have taken on the responsibility of developing and operating e-commerce sites, and individual stores and companies that have previously conducted retail business only through brick-and-mortar stores will be able to utilize the developed platform and sell products on e-commerce sites by affiliating with the company. For organizations that sell products in this manner, it is necessary to consider which affiliated store to assign the requested order to after the e-commerce site company receives an order from a customer. There are several things to consider when assigning orders. Typical examples include whether the assigned affiliated store can fulfill all orders, whether the distance between the assigned affiliated store and the delivery destination is realistic. Currently, in some cases, operators manually perform part of the task of assigning orders to each affiliated store. To address the above problem, we developed an order assignment algorithm based on the proposed method using Voronoi tessellations, and thereby developed a system that automatically assigns orders to affiliated stores, replacing the current order assignment work currently performed manually by operators. We conducted numerical experiments using actual organizational data and verified how practical the results were by comparing to operator performance. As a result, the order assignment algorithm based on Voronoi tessellations showed superior results compared to operator performance.

Technological Innovation and Cyclical Fluctuation in Industry Dynamics

Diana HweiAn Tsai

National Yang Ming Chiao Tung University, Taiwan; Diana@nycu.edu.tw

The emerging technological innovations in AI, 5G, and information technologies have propagated new market opportunities for all industries, and the AI augmenting design and manufacturing of semiconductors have then been applied and spilled over to other related high-technology industries. This paper fills the gap in the industry econometrics literature that has not received much empirical attention in the presence of uncertainty and expectation mechanisms and the impacts on industrial dynamics. In markets with cyclical fluctuations and demand uncertainty, firms may have different dynamic decision rules facing upturns and downturns of industry cycles. We formulate a new dynamic framework with uncertainty and expectation mechanisms by integrating regime-switching industry cycles for cyclical fluctuation and demand uncertainty. Drawing on firm-level data of Taiwan's high-technology industries, we trace how Taiwan's high-technology companies upgraded their dynamic capabilities in facing asymmetric cyclical behavior and endogenous demand uncertainty. Explicitly incorporating the Markov regime-switching mechanism, we measure the firm's dynamic adjustments when facing upturns and downturns of industry cycles. We also evaluate the firms' dynamic decision rule and the resulting procyclical or counter-cyclical behavior in industry cycles. By unpacking the complex structure of industry cycles, the study extends the existing understanding of how some high-technology industries are more cyclical than others and attributes to capacity expansionary competition as a strategic competition. We conclude by highlighting the implications for research on the adjustment speed of essential inputs and the challenge of optimal forecasting of the expansionary and contractionary phases of the industry cycles.

Averages of team rating in sports

Kei Takahashi, **Takanhiro Kuwayama**

Fukuoka Institute of Technology, Japan; takahashi@fit.ac.jp

This paper introduces several averages in dynamic team ratings in sports. In last year's presentation, we showed desirable properties in dynamic team ratings and proposed a simple model. However, this model had the disadvantage that the rating of a team in a given match depends only on the ratings of that team and the opposing team one match earlier, thus the ratings tend to fluctuate. Therefore, this study proposes "averages" equivalent to a moving average or an exponential smoother in normal time series. Specifically, we introduce daily and match windows and consider ratings by averages between them. Ratings based on these averages are applied to several team sports, and the results are compared. Finally, the final ratings obtained are compared with the results of the pre-season matches.

WE 15: Retail Supply Chains

Time: Wednesday, 04/Sept/2024: 4:30pm - 6:00pm · *Location:* Wirtschaftswissenschaften 0534
Session Chair: Alper Nakkas

The window fillrate in a period review inventory system

Michael Dreyfuss, Yahel Giat
Jerusalem College of Technology, Israel; dreyfuss@jct.ac.il

We explore the challenge of spares allocation within a complex inventory system encompassing multiple items and locations, all under periodic review. The primary aim is to enhance service efficiency by maximizing the window fill rate, which denotes the likelihood of promptly serving a random customer within a specified time frame. The window fill rate offers a nuanced metric, accounting for customers' willingness to endure some waiting time before being attended to.

Our study delves into the formulation of the window fill rate and reveals its varying behavior concerning the number of spares, manifesting as either a constant, concave, or convex-concave function contingent upon the acceptable wait time. Leveraging these insights, we devise an effective algorithm to optimize spares allocation within predefined budget constraints or target window fill rates. Notably, our analysis suggests that when the acceptable wait time or budget is limited, spares tend to concentrate in select locations or item types, while others may remain unallocated.

Furthermore, we substantiate our findings through numerical simulations using two distinct large-scale synthetic scenarios. These simulations serve to elucidate the comparative costs associated with periodic versus continuous review strategies, illustrating the potential advantages of employing the window fill rate as a criterion for optimality. The numerical analysis underscores both the intricacies inherent in optimizing the window fill rate and the tangible savings achievable through its judicious utilization in spares allocation decisions.

Optimizing assortment and inventory on shelves when products perish

Alexander Hübner[1], Lena Riesenegger[1], Manuel Ostermeier[2]
[1]Technical University of Munich, Germany; [2]University of Augsburg, Germany; alexander.huebner@tum.de

Optimizing retail assortments is essential to maximize revenues, but also can have an impact on inventory ages and therefore product expiration. The limiting condition for assortment decisions is the shelf space of retailers. Assuming a constant available, but in size restricted shelf space, the assortment size also defines how much shelf space each product gets, and therefore how much items of each product can be stored on the shelf. That is why assortment planning is also important in terms of inventory management. Especially for perishable products, the inventory level on the shelf has to be carefully chosen in order to prevent deteriorating overstocks. Current literature considers single-period assortment and shelf space models, despite products can be stored and replenished over multiple sales periods, leading to different expiration dates on the shelf. We contribute with an assortment and shelf space model that considers replenishment and customer withdrawal over several periods, taking into account stochastic demand, space elasticity, substitution effects and customer's freshness preferences. To solve the model, we use an iterative heuristic approach with a recurring update of demand to account for substitution effects and their impacts on the assortment and shelf space decisions.

Shelf-life requirements and their impact on contractual agreements in perishable-product supply chains

Sandra Transchel, Mahyar Taheri, Andreas Gernert
Kuehne Logistics University, Germany; sandra.transchel@klu.org

Two primary goals of grocery retailers when managing perishable products (e.g., food) are (i) to offer products with a high remaining shelf life to consumers, as those are perceived to be of high quality, and (ii) to minimize waste driven by products that exceed their maximum remaining shelf life. Both goals prompt retailers to integrate a minimum remaining shelf-life requirement, known as "Minimum Life on Receipt" (MLOR), into the contracts with their suppliers. However, little is known about how such an MLOR requirement affects the contractual agreement between retailers and food producers and how it further affects replenishment and production decisions, profitability, and waste of the retailer and the food producer. In this paper, we investigate how an MLOR requirement of the retailer affects the operational performance of a wholesale price contact in a two-echelon perishable-product supply chain. We consider that both the retailer and the food producer follow a basestock policy, where the basestock levels are optimized depending on the wholesale price set by the food producer and the MLOR requirement. Our results challenge widely accepted findings that retailers benefit from organizing their inventory management following a first-in-first-out (FIFO) issuing policy compared to a last-in-first-out (LIFO) policy.

Behavioral Implications of Bilateral Relationships on Supply Chain Contracting

Alper Nakkas[1], Lei Hua[2], Kay-Yut Chen[1], Jason Xianghua Wu[3]
[1]University of Texas at Arlington, United States of America; [2]University of Texas at Tyler, United States of America; [3]University of New South Wales, Australia; nakkas@uta.edu

This paper investigates the impact of bilateral relationships on procurement and competition incentives in a supply chain environment from a behavioral perspective. We focus on a two-retailer-two-supplier market where retailers negotiate supply procurement contracts with their potential suppliers. In our model, potential trade partners are determined by a bilateral relationship network, which is a bipartite graph where nodes represents firms and links rep- resents bilateral relationships among firms, and not every downstream retailer has links with every upstream supplier. We first derive the bargaining equilibrium outcome as theoretical benchmark and then conduct a laboratory experiment to confirm the results from theoretical benchmark. Our experimental data suggest systematic deviations from the theoretical benchmark and reveal behavioral regularities on contracting behavior. In particular, we show that firms with more (less) potential partners and/or higher (lower) perceived values tend to earn more (less) than theoretical benchmark. We develop a new behavioral theory, referred to as desperateness model, where a firm's unfavorable bargaining position inflicts additional distress to the firm. This additional stress amplifies the bargaining incentives of firms in such a way that the firms with favorable bargaining positions can take advantage of the desperateness of firms with unfavorable positions to extract additional profit. We demonstrate that our desperateness theory explains and predicts the firms' supply contract bargaining behavior well.

WE 16: Flow Shop Production

Time: Wednesday, 04/Sept/2024: 4:30pm - 6:00pm · *Location:* Wirtschaftswissenschaften 0540
Session Chair: Stefan Helber

The impact of lot streaming in hybrid flow shop scheduling with setup times

Maximilian Hubmann[1], Markus Höfling[1], Daniel Zähringer[1], Janis Neufeld[1,2]

[1]Technische Universität Dresden; [2]Otto-von-Guericke-Universität Magdeburg; maximilian.hubmann@mailbox.tu-dresden.de

In lot streaming, the production lot is divided into smaller batches, each of which can be processed separately through the manufacturing system. Recent studies have shown the practical relevance of lot streaming by providing greater flexibility in scheduling and allowing for more efficient use of available resources. This research addresses the potential of lot streaming within the hybrid flow shop scheduling problem by integrating setup times, with a focus on minimizing the makespan. The study proposes a mixed integer linear programming formulation to capture the complexity of the problem and employs a metaheuristic iterated greedy algorithm to efficiently find near-optimal solutions. A key aspect of this investigation is the consideration of (non-anticipatory) setup times, which occur between every changeover of sublots and add a layer of realism to the problem. The effectiveness of the proposed approach is evaluated through computational experiments comparing different local reinforcement strategies and sublot assignment methods. The results allow quantification of the potential of lot streaming within hybrid flow shops. Insights from the experiments highlight the impact of factors such as the size and number of sublots on the quality of the solution, suggesting potential avenues for practical implementation in multi-stage manufacturing systems.

Optimization of distributed permutation flowshops considering eligibility constraints, qualification opportunities and limited transfer options

Martin Schönheit, Rainer Lasch

TU Dresden, Germany; martin.schoenheit@tu-dresden.de

The trend to distribute production facilities across several countries, due to globalization and increasing customer demands, increases the complexity of operational processes and presents companies with the challenge of effectively managing these production networks. Due to the complexity of the scheduling problems, there has been a growing research interest in investigating centralized solution approaches for production networks. This paper extends the fundamental problems by integrating factory eligibility constraints as well as options to qualify factories by relocating tools or personnel for a distributed permutation flow shop problem. A bi-criteria optimization problem is analyzed to minimize weighted total tardiness and total cost. Another unique feature is the integration of pricing of carbon emissions due to production, tool transfer and transport to the customer.

Factory-dependent due dates, limited transport capacity for tool transfer, and transport time windows strengthen the practical relevance. A computational study is used to analyze the impact and dependencies of critical influencing variables such as customer location, tool and product weight and production process intensity. In addition, the effect of restricting the tool transfer options on the Pareto front is analyzed. A key implication is the dependence of scheduling decisions on critical contextual factors such as customer location, degree of factory eligibility, and tool and product weight, highlighting the need to consider transportation as a decisive factor in distributed scheduling problems. Consequently, a promising area for further research is the potential to investigate the integration of information on critical instance parameters to guide the search in approximation-based solution methods.

Design of unreliable flow lines: How to jointly allocate buffer space and spare parts

Florian E. Sachs[1,2], Gudrun P. Kiesmüller[1], Stefan Helber[3]

[1]Technical University of Munich; [2]University of Cologne; [3]Leibniz University Hanover; florian.sachs@uni-koeln.de

The design of flow lines is an extensive area of research whereby most publications focus on buffer allocation to cope with random influences like breakdowns or random differences in processing times. In addition, spare parts can directly increase the machines' availability. However, only a few papers consider the simultaneous optimization of buffer space and the possible number of spare parts in stock. The literature hardly even considers the evaluation of such systems. We are the first to introduce the joint optimization of buffer space and spare parts for flow lines of arbitrary length. First, we aim to allocate buffer capacities and spare parts efficiently. Since the buffer allocation problem is NP-hard, we can expect only to find near-optimal solutions. Second, we demonstrate the algorithmic behavior of different greedy and metaheuristics on this design problem. We illustrate how to exploit the problem structure to solve it almost optimally. Third, we generate managerial insights into allocating spare parts in manufacturing systems with buffers. We show that spare parts tend to be more effective when arranged at or near the center of a flow line, as it is already known for buffers. Moreover, we provide details on the combined buffer and spare part allocations.

WE 17: Project Scheduling Applications

Time: Wednesday, 04/Sept/2024: 4:30pm - 6:00pm · *Location:* Wirtschaftswissenschaften 0544
Session Chair: Baptistin CARVIN

Ergonomic-economic project scheduling in construction: The case of PV installation

Jannis David, Thomas Volling
Technische Universität Berlin, Germany; david@tu-berlin.de

The prevalence of work-related musculoskeletal disorders (WMSDs) poses a significant challenge for construction companies. These disorders not only cause considerable physical pain and suffering for affected workers but also lead to decreased productivity, increased absenteeism, and escalating healthcare costs for employers. The situation is exacerbated by ongoing labor shortages and shifting workforce demographics. To address this issue, we present a novel multi-objective model designed to optimize construction projects both ergonomically and economically.

The proposed Bi-MRCPSP model expands upon the multi-mode resource-constrained project scheduling problem (MRCPSP) by incorporating equipment modes for differently skilled workers in addition to execution modes for jobs. We consider three objectives: (1) project makespan, (2) project cost, and (3) workers' occupational metabolic energy expenditure (OMEE). In the context of these objectives, three strategies to improve ergonomics are integrated: (1) additional workforce, (2) planned recovery breaks, and (3) the use of exoskeletons for mechanical support.

Applying the model to the installation of photovoltaic (PV) systems on houses demonstrates its validity and provides practical insights. Results from a Pareto front analysis reveal the potential of exoskeletons as a supportive technology in construction projects, providing valuable insights for decision-making regarding project planning and technology investments. A key finding is that exoskeletons enable more time- and cost-efficient ergonomic workplace designs, encouraging both companies and researchers to explore this technology further.

A Dantzig–Wolfe decomposition approach for solving an integrated project and personnel scheduling problem

Brede Sørøy, Henrik Andersson, Anders N. Gullhav
Norwegian University of Science and Technology, Norway; brede.soroy@ntnu.no

We are considering an integrated project and personnel scheduling problem with equipment transportation. It consists of one or several projects whose activities need to be completed to finish the projects. The activities are multi-modal and discretely preemptive, and there are precedence constraints that need to be respected. Furthermore, we have personnel and equipment that need to be allocated so that the activities' resource demands are satisfied.

Due to the complexities arising when scheduling the projects and resources simultaneously, a Dantzig–Wolfe reformulation is proposed. This method decomposes the problem into a master problem and one or several subproblems to find improving solutions. In our case, the allocation of personnel and equipment is taking place in the master problem, while the projects are scheduled in the subproblems by solving a preemptive project scheduling problem without resource constraints. As the projects are independent of each other, the subproblems are given one project each to find improving solutions that are then provided as columns to the master problem.

Using column generation, we are able to strengthen the linear relaxation of the integrated problem, which in turn yields good solutions more efficiently. Furthermore, this approach shows promising results regarding to find better solutions compared to a commercial solver.

Hybrid three-phase method for MRCPSP with generalized precedence and sequence dependent setup time

Baptistin CARVIN, Odile Bellenguez, Guillaume Massonnet
IMT-Atantique / Vif, France; baptistin.carvin@imt-atlantique.fr

This work addresses a problem inspired from scheduling problems in the food industry, with specific precedence graphs due to the workshop structure.

The problem can be modelled as a Multi-mode Resource Constrained Project Scheduling Problem (MRCPSP) with machine and sequence-dependent setup times, generalised precedence to represent waiting time (for example letting a dough rise or a baking tin cool down before the next step) and non-renewable resource may be delivered during the production period (e.g. perishable raw ingredients).

To tackle this problem we proposed a multiphase method using both linear and constraint programming derived from Unrelated Parallel Machine Scheduling dividing it in 3 sub-problems : assigning tasks to machines, ordering tasks on each machine and finally, scheduling each task.

The first step is to assign tasks to processing modes and by extension to machines while minimising the working time. This step must take into account processing time of the task and an estimated setup time.

The second step is comparable to TSP and try to minimize the working time on each machine individually by sequencing its set of assigned tasks by adding the final setup times in the model.

The last phase is meant to arbitrate resource concurrency but will also apply the final scheduling by taking into account the generalized precedences.

We will present numerical results and further improvements to the method, particularly performance comparisons between linear and constraint programming solving of each phase and bound approximation in the two first phases.

WE 18: Energy Flexibility

Time: Wednesday, 04/Sept/2024: 4:30pm - 6:00pm · *Location:* Theresianum 0601
Session Chair: Christine Nowak

Energy Flexbility of Production Processes

Stefanie Samtleben, Julien Brandes

Fraunhofer IFF, Germany; julien.brandes@iff.fraunhofer.de

This study investigates the relationship between energy supply and production processes, with a focus on energy-flexibility. The main goal is to exploit the economic and ecological potential of flexible production facilities in manufacturing. Expanding on this, the research evaluates how optimized factory layouts can influence the integration of renewable energy sources. Our study advances by employing a mathematical optimization model, specifically a Mixed-Integer Linear Programming (MILP) approach. This model aims to assess the correlation between the energy consumption of production processes and the residual load, optimizing what we refer to as the "Relocation Coefficient." It indicates the proximity of the energy usage profile to the residual load, incorporating our use of a linearized version of the Blarke coefficient as the objective function. To illustrate the application of this model, we focus on a specific case study involving an electrolyzer manufacturer. Within their energy-intensive production processes, we specifically analyze the galvanization of components. We consider a period of one month as the scenario, with simulated energy generation data in the vicinity of the production facilities under consideration, with a temporal resolution of 15 minutes. Subsequently, the order volume and layouts can be varied to achieve production optimization, with the Blarke coefficient serving as an evaluation criterion. By systematically examining different layouts and production scenarios, we were able to achieve and demonstrate optimization in the correlation between residual load and energy consumption during production. This optimization signifies an enhancement in the utilization of renewable energy sources.

Optimization of Green Hydrogen Supply Chains for Sustainable Aviation: Multi-Period Network Design Model with Seasonal Temporal Resolution

Akin Ögrük, Christian Thies

TUHH, Germany; akin.oegruek@tuhh.de

Hydrogen-based propulsion concepts for aircraft are considered a promising technology towards the decarbonization of aviation. While the development of respective aircraft models is in progress, questions regarding the supply network of green hydrogen are arising. We present a multi-period mixed-integer programming model for the hydrogen supply chain network design problem focusing on the aviation sector. The model minimizes the total network cost by making strategic decisions (e.g. suppliers, locations, capacities, transportation infrastructure) and tactical decisions (e.g. hydrogen flows, storage quantities) at different temporal resolutions. Our model formulation considers the spatially and temporally varying supply and demand of hydrogen, the techno-economic characteristics of hydrogen storage, liquefaction and transportation (e. g., economies of scale), as well as the specific requirements of hydrogen handling (e.g., losses). Model application is illustrated for German airports with local production and hydrogen import options, considering the projected development of the European Hydrogen Backbone pipeline infrastructure. Optimal network designs and results are presented and analyzed for different hydrogen supply and demand scenarios.

Using the flexibility of the thermal mass of buildings to assess emission reduction potentials—a case study for Ireland and Germany

Christine Nowak[1], Donal Finn[2], Valentin Bertsch[1]

[1]Ruhr-Universität Bochum, Germany; [2]University College Dublin, Ireland; Christine.J.Nowak@ruhr-uni-bochum.de

Although the expansion of renewable electricity generation has significantly progressed in Europe, the shift to renewable heating technologies has been slower. Heat pumps provide the possibility to exploit synergies between the electricity and heating sectors. As it is imperative to reduce carbon emissions as quickly as possible, one solution can be integrated energy system flexibility options when using heat pumps. This will allow for the utilisation of electricity when there are many renewable energy sources available in the electricity mix, resulting in fewer carbon emissions.

Therefore, the research questions of this work are: How much can the operation of heat pumps reduce carbon emissions and decouple energy demand and supply by making the heating demand of building occupants more flexible, such as through the thermal mass of buildings? Additionally, how do geographical variations, e.g. between Ireland as one of the northern islands of Europe and Germany as a country on the European mainland, affect the potential for carbon emission reductions?

A detailed energy system model for residential buildings in Ireland and Germany is developed using the open-source optimisation framework called Backbone. The model considers typical parameters for residential buildings in both countries to create a building structure and generate endogenous heating demands. The thermal flexibility of building masses will be analysed to shift heating demands based on variable electricity emission factors. By evaluating emission reduction potentials, insights into the path to climate neutrality are gained.

WE 19: Multi-Criteria, Multi-Objective Decision-Support in Energy and Sustainability

Time: Wednesday, 04/Sept/2024: 4:30pm - 6:00pm · *Location:* Theresianum 1601
Session Chair: He Huang

Introducing MCDA calculator: A streamlined, web-based MCDA calculation tool

He Huang, Peter Burgherr
Paul Scherrer Insititut, Switzerland; he.huang@psi.ch

Multi-Criteria Decision Analysis (MCDA) represents a crucial approach to decision-making, offering systematically structured methods for addressing complex issues across various contexts. However, the practical application of MCDA is often hindered by the specialized nature of existing software so-lutions tailored to specific MCDA methods. While these tools are beneficial in providing detailed procedural guidance, they can introduce inefficiencies for experienced practitioners and require additional learning for new users. Recognizing these challenges, this study presents the MCDA Calculator web tool, a decision support system (DSS) designed to fill current MCDA applica-tion software gaps. Our tool integrates various MCDA methodologies into a single, intuitive platform, minimizing the need to switch between different software and reducing the learning curve associated with each. By providing a streamlined calculation structure that accommodates multiple MCDA methodologies within a consistent process flow, the MCDA Calculator en-hances usability for practitioners. This is intended to improve the efficiency and effectiveness of decision-making processes and to facilitate a more ho-listic and flexible approach to the application of MCDA.

Multi-criteria approaches in energy system optimisation models – overview and case studies

Jonas Finke, Valentin Bertsch
Chair of Energy Systems and Energy Economics, Ruhr-Universität Bochum, Germany; jonas.finke@rub.de

Energy system models are key tools to support decision-making for the energy transition. Traditionally, they focus on the techno-economic sphere by generating the least-cost solution that satisfies demand and meets technical requirements. This approach neglects that a variety of decision-makers and stakeholders are involved in the energy transition, each of whom has multiple and potentially conflicting interests. Considering multiple decision criteria in energy system models can address this shortcoming and provide improved decision support.

We identify five multi-criteria approaches used in in energy system optimisation models: pure ex-post evaluation, simple constraints, monetisation, modelling to generate alternatives and multi-objective optimisation. We present mathematical formulations and selected case studies for each of the five approaches. Finally, we synthesise requirements, strengths and limitations of the approaches and point towards promising directions for future work.

Stakeholders integration for MCDA sustainability assessment of energy technologies: a use case in energy storage

Laura Sofia Mesa Estrada[1], Martina Haase[1], Manuel Baumann[1], Christina Wulf[2]
[1]Karlsruhe Institute of Technology, Germany; [2]Forschungszentrum Jülich, Germany; laura.mesa-estrada@kit.edu

The global energy transition requires a high share of intermittent renewable energy in many countries, which poses a challenge to energy supply and system reliability. There are different strategies to mitigate these fluctuations, among which large-scale deployment of energy storage plays a crucial role. In addition to the technical challenge, these transitions involve different types of conflicts, such as resource criticality and climate objectives. Decision-making in this context involves different sectors of society with different priorities and requires a tool such as Multi-Criteria Decision Analysis (MCDA) to facilitate communication between citizens, decision-makers and technology developers. Methods such as mediated modelling techniques, decision conferences and decision analysis interviews are some of the existing approaches used in participatory MCDA. Despite their successful description and application, analysts agree on the barriers to further application of these participatory formats: the need for significant effort and resources to implement them. This research aims to develop and implement an interactive decision support tool (software) to facilitate the integration of stakeholders in MCDA for sustainability assessment. Through real-time interaction of stakeholder preferences with the MCDA model, this work aims to accelerate and support transparent decision-making processes. Based on the selection requirements of the MCDA method for sustainability assessment, the ELECTRE III method is used to model the decision problem. This paper presents the developed interactive decision support tool and its application in the EU project StoRIES for MCDA sustainability assessment of energy storage.

Prospective multi-criteria analysis in the water-energy nexus

Sebastian Schär, Jutta Geldermann
University of Duisburg-Essen, Germany; sebastian.schaer@uni-due.de

Water and energy are resources that play a crucial role in the functioning of societies. However, the demand for water and energy is increasing rapidly due to population growth and economic development, leading to challenges in supply and allocation under increasing scarcity. To add, the water and energy sector are interrelated in many processes. The water-energy nexus refers to these interrelations of the water and energy sector.

Strategic decision making in the water-energy nexus can be complex and subject to uncertainty, since there may be trade-offs or conflicting goals that need to be balanced and multiple, interrelated factors that need to be considered when evaluating the consequences of decisions. The methods of multiple criteria decision analysis (MCDA) provide a systematic, structured approach to evaluate and compare alternative options based on multiple objectives and can facilitate well-informed decisions. Furthermore, MCDA methods allow for the explicit consideration of multiple stakeholders and provide means for consensus facilitation.

We present a framework based on system dynamics and the Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) for strategic decision-making in the water-energy nexus to address interrelationships of the water-energy nexus in the assessment of alternatives. Qualitative system dynamic approaches are applied to reveal interdependencies. A case study for water resources management in the Middle East illustrates how the framework can enable a prospective assessment of technical solutions in the water-energy nexus.

WE 20: Natural Language Processing

Time: Wednesday, 04/Sept/2024: 4:30pm - 6:00pm · *Location:* Theresianum ZG 0670
Session Chair: Kanchan Awasthi

Natural Language Processing Analysis of Sustainability Disclosures and Corporate Operation Efficiency

Gladie LUI

ESCP Business School; glui@escp.eu

In the last decade, stakeholders have been pressuring firms to take more initiative with their sustainability agendas, leading to a booming demand for firms' non-financial information disclosure. Corporate Social Responsibility (CSR) performance is increasingly used to evaluate organizations' management quality, identify their exposure to risk, and assess their ability to leverage business opportunities. This leads to the question: Does CSR affect corporate operation efficiency. This study analyzes Singaporean companies' sustainability reports for 2015 to 2021 and their relation with corporate operational efficiency. Three research questions are addressed:

RQ1: What are the disclosure characteristics including topic components, sentiment and readability in sustainability reports during the period of study?

RQ2: How do those topics identified in RQ1 relate to corporate operation efficiency score computed using Data Envelopment Analysis (DEA)?

RQ3: How do moderating factors including product market competition, ESG risk scores and board gender diversity impact findings from RQ2?

The sample consists of 206 sustainability reports from companies included in the Stratis Time Index, the benchmark index for Singapore's stock market. Several NLP methods are employed – Tokenization and Latent Dirichlet Allocation (LDA), readability assessment, and sentiment analysis. The second objective of this study is to determine the relation between sustainability disclosures and DEA operation efficiency scores. After controlling for Return on Assets (ROA), Market Value (MV), firm age, industry and fixed year effect, the findings suggest a positive association. Furthermore, analyses are conducted to study the moderating effects of external monitoring and corporate governance mechanism on the magnitude of the association.

Operational adaptation of social sustainability measurement methods in supply chains: A logit-regression-based approach on text mining data of German Company Reports

Tonio Kawase

WHU - Otto Beisheim School of Management, Germany; tonio.kawase@whu.edu

New regulatory frameworks such as LkSG (Germany) or CSDDD (EU), increase the need for tracking and build-up of KPI frameworks in companies with physical Supply Chains to disclose the level of social sustainability (e.g., child or forced labor).

Due to lack of KPI frameworks and methodologies provided from regulatory side (based on legal document analysis), the methods in practical use by companies subject to strict legal requirements, were collected and analysed in a longitudinal design by a self-programmed text mining tool on German public annual reports.

The annual report results were combined with a logit regression approach to uncover patterns between disclosure methodologies in use and social dimensions of ESG Ratings as a measure of success, to give operations research (OR) scholars and practitioners a guidance on current dynamics and trends in an emerging field reacting to new legal requirements ensuring basic human rights in supply chains.

We focus on exploring the adaptation and success of certain disclosure methods for Social Sustainability, shortcomings of the existing studies, and providing insights for practitioners as well as future directions for researchers.

The study contributes to the OR field by offering an empiric view on methodologies and KPI frameworks, as well as industry specific norms to optimize a firm's operations for success in the social sustainability dimension.

Exploring sustainability in Patents using Natural Language Processing: An application in Textile Sector

Kanchan Awasthi, Krunal Padwekar, Subhas Chandra Misra

Indian Institute of Technology Kanpur, India; awasthi.kanchan2@gmail.com

Textile sector is one of the most polluting and waste generating sectors. Pertinent efforts have been made to reduce its environmental impact and bring sustainability to its operations. Government is continuously promoting patent granting and filing in this sector to develop innovative solutions for sustainability. Hence, there is continuous increase in the number of patents published in the last decade. These patents are commonly described in text formats that can be analysed by Artificial Intelligence tools such as Natural Language Processing. In this study, an analysis of patents in textile field is conducted to extract keywords from patent abstracts using algorithms such as TF-IDF and TextRank. Identified keywords are used for weight computation and string matching. Weight computation is done by calculating the frequency of each term using TF-IDF and Text Rank whereas string matching is done using Levenshtein-distance to reduce repetition of terms. Finally, network analysis is performed to understand the relations between keywords and to find the most influential technologies for sustainability in textile sector.

WE 21: Airport and Airline Applications 3

Time: Wednesday, 04/Sept/2024: 4:30pm - 6:00pm · *Location:* Nordgebäude ZG 1070
Session Chair: Sinan Gürel

Improving Airline Destination Coverage through Airport Slot Allocation

Christian Truden, Margaretha Gansterer
University of Klagenfurt, Austria; christian.truden@aau.at

Due to the escalating congestion at airports, there has been a growing interest in using optimization methods for airport slot allocation and flight scheduling. Level 2 and 3 airports nowadays have a substantial surplus of demand relative to airport capacity, which requires sophisticated slot allocation. This process is not only a computationally complex task but needs to satisfy the requirements of different players following individual objectives. The resulting allocation of slots and subsequent flight schedules significantly impacts the market power of airlines. From the passengers' perspective, the key consideration is connectivity, emphasizing the importance of viable connections between destinations. We propose an innovative slot allocation model that prioritizes destination coverage while considering limitations on market power for participating airlines. Based on an extensive computational study, we elaborate on how varying degrees of market power restrictions can positively or negatively influence connectivity.

Fleet and Tail Assignment under Uncertainty

Lukas Glomb[2], Frauke Liers[1], Florian Rösel[1]
[1]Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany; [2]Fraunhofer-Institut für Integrierte Schaltungen IIS, Erlangen, Germany; florian.roesel@fau.de

Airlines solve many mathematical optimization problems and combine the resulting solutions to ensure smooth, minimum-cost operations, e.g., the Tail Assignment Problem to determine an optimal assignment of aircraft to a flight schedule. For these to be effective, the available data and forecasts must reflect the situation as accurately as possible. However, the underlying plan is subject to severe uncertainties: Staff and demand uncertainties can even lead to flight cancellations or result in entire aircraft having to be grounded. Therefore, it is advantageous for airlines to protect their mathematical models against uncertainties in the input parameters. We present two computationally tractable and cost-efficient robust models and solution approaches:

First, we set up a novel mixed integer model for the integrated fleet and tail assignment, which ensures that as few subsequent flights as possible have to be canceled in the event of initial flight cancellations. We then solve this model using a procedure that ensures that the costs of the solution remain considerably low.

Our second model is an extended fleet assignment model that allows us to compensate for entire aircraft cancellations in the best possible way, taking into account rescheduling options. We demonstrate the effectiveness of both approaches by conducting an extensive computational study based on real flight schedules of a major German airline.

Both models deliver stable, cost-efficient solutions, which significantly reduce follow-up costs in the case uncertainties arise.

Tail Assignment Problem with Hour-to-Cycle Ratio Considerations

Sinan Gürel, Çiya Aydoğan
Industrial Engineering Department, Middle East Technical University, Turkiye; gsinan@metu.edu.tr

Airlines are responsible for managing the hour-to-cycle performance of their aircraft on operational lease. For a leased aircraft, the leasing contract usually specifies target hour-to-cycle ratios that must be met. Supplemental rental payments are required if the aircraft cannot achieve the target ratio. This study presents a tail assignment problem that takes into account the accumulated flight hours and flight cycles of the aircraft and incorporates penalty costs for failing to meet the target hour-to-cycle ratios. Considering hour-to-cycle ratios in the tail assignment problem adds complexity to the aircraft scheduling process. It also results in nonlinear expressions to the mathematical model. This study presents two possible reformulations of the problem, one using McCormick linearization and the other using second-order conic inequalities. Computational results indicate that mathematical formulation using McCormick linearization performs better than conic reformulation. Furthermore, numerical results demonstrate that disregarding hour-to-cycle ratio targets in aircraft scheduling can lead to drastic deviations from target ratios.

WE 22: Emerging Trends in Mobility

Time: Wednesday, 04/Sept/2024: 4:30pm - 6:00pm · *Location:* Nordgebäude ZG 1080
Session Chair: Gerhard Hiermann

Optimal deployment of inductive charging segments for autonomous and electric shuttle services in rural areas

Paul Bischoff[1], Salma Hammani[2], Patrick Klein[1], Maximilian Schiffer[1,3]
[1]School of Management, Technical University of Munich, Germany; [2]Ecole des Ponts Paris Tech; [3]Munich Data Science Institute, Technical University of Munich, Germany; paul.bischoff@tum.de

Electric vehicle (EV) penetration in public bus and shuttle systems is rising due to EVs' favorable tail-pipe emissions. However, conventional conductive charging limits vehicle utilization and requires drivers to leave the vehicle to connect to the grid. Inductive charging presents a solution to these challenges by allowing charging while driving and eliminating the need for drivers. Against this background, we study the stationary and dynamic inductive charging segment location problem for electric shuttle fleets within the scope of the project, MILAS, that deploys such shuttles accessible to the public in Bad Staffelstein, Germany. We assume fixed public transportation stop sequences and timetables, and determine cost-optimal charging segment configurations with respect to energy demand and construction costs, while avoiding conflicting stationary charging operations. We present an iterative local search with a structured perturbation procedure to keep the number of explored configurations tractable. We solve the resulting subproblems as resource-constrained shortest path problems via an efficient implementation of a label setting algorithm Herein, we check dominance in a lazy fashion and accelerate the dominance check by maintaining and exploiting local bounds. We outperform a commercial solver on a set of benchmark instances. Furthermore, we study the value of decentral energy storage leading to time-dependent energy prices with high volatility and investigate the value of shared charging segments that require deviations from some shuttles' shortest paths for the network in Bad Staffelstein. We present results for the actual project scenario in which two shuttles are deployed and for scenarios with larger fleets.

Integrated Balanced and Staggered Routing in Autonomous Mobility-on-Demand Systems

Antonio Coppola[1], Gerhard Hiermann[1], Dario Paccagnan[2], Maximilian Schiffer[1,3]
[1]School of Management, Technical University of Munich; [2]Department of Computing, Imperial College London; [3]Munich Data Science Institute, Technical University of Munich; antonio.coppola@tum.de

Autonomous mobility-on-demand (AMoD) systems offer a solution to urban congestion through a centrally controlled fleet of autonomous vehicles that provide door-to-door mobility services. By replacing individual human-driven vehicles with a centrally coordinated autonomous fleet, AMoD systems can enhance traffic flow following two strategies: balanced routing and staggered routing.

Balanced routing distributes AMoD traffic across alternative road segments of the street network to spatially even out traffic. In contrast, staggered routing strategically postpones vehicle departures to smooth out peak demands on certain routes, thereby balancing travel demand over time.

While a consistent body of literature on balanced routing exists, staggered routing is a relatively new area of research. Preliminary investigations have examined the potential for congestion reduction through coordinated AMoD vehicle departures assuming centrally pre-determined paths, thus leveraging balanced routing in a sequential approach.

In this study, we propose an integrated framework for balanced and staggered routing. First, we formalize the problem of simultaneously determining the optimal routes and departure times for AMoD trips to minimize induced congestion. Second, we introduce a novel metaheuristic algorithm designed to solve large-scale problem instances. Finally, using real-world taxi data, we conduct a case study in Manhattan, New York, to examine the trade-offs between altering routes and adjusting departure times. Moreover, we quantify the additional congestion that an integrated approach to balanced and staggered routing mitigates compared to sequential strategies.

Epidemic-aware public transport network design

Gerhard Hiermann[1], Benedikt Lienkamp[1], Maximilian Schiffer[1,2]
[1]Technical University of Munich, Germany; [2]Munich Data Science Institute, Technical University of Munich; gerhard.hiermann@tum.de

Transportation networks are integral for the movement of people and goods. The recent pandemic showed the challenges of maintaining and managing infrastructure, especially passenger transportation networks, to preserve essential basic services and limit economic harm while confining epidemic spreading. Herein, designing adaptable networks based on epidemic states to balance optimal functionality and reduce infections will become crucial in future outbreaks.

In this work, we address this balancing issue by studying an epidemic-aware network design problem. We assume passenger flows are infection-level agnostic and aim for the quickest route through the available network. We introduce epidemic-spreading aware constraints on arc utilization.For the network resources, we include decisions on transit line availability, including vehicle quantities, dimensions, and frequencies. Our goal is to find a network configuration to minimize the total passenger travel time while respecting capacity limitations and accounting for different epidemic infection scenarios.

We devise a robust branch-and-price approach using a path-based reformulation to solve city-scale instances and analyze the impact of the epidemic-aware formulation. We apply our solver to a real-world case study for the city of Munich and derive managerial insights.

WE 23: Scheduling in Transportation 2

Time: Wednesday, 04/Sept/2024: 4:30pm - 6:00pm · *Location:* Nordgebäude ZG 1090
Session Chair: Xingyi Wang

Route planning with heterogeneous environmental preferences of shippers

Justin Wittig, **Christian Bierwirth**

Martin-Luther-Universität Halle-Wittenberg, Germany; justin.wittig@wiwi.uni-halle.de

Due to the influence of indirect emissions in sustainability reporting, there is an incentive for industrial shippers to choose climate-friendly transport options. As a result, freight forwarders are faced with the long-term task of converting their fleets to lower-emission vehicles. This process involves a fluid change in the fleet, with conventionally powered and lower-emission vehicles being used in parallel. Route planning is now faced with the problem of reconciling this heterogeneous fleet with divergent customer preferences. This paper provides a planning model for the design and deployment of a mixed fleet of conventional and lower-emission vehicles. Transport services performed by lower-emission vehicles are priced higher but receive lower emission reports. Our model attends to increase the overall customer satisfaction. It is tested under varying customer preferences regarding cost and emissions and under changing compositions of fleets. Our computational results indicates that solutions beyond minimum cost or minimum emission plans can be more suitable in order to match heterogeneous customer preferences.

Allocation and Routing of Service Technicians with Different Skill Levels

Xingyi Wang, **Gudrun P. Kiesmüller, Rainer Kolisch**

Technische Universität München, Germany; xingyi.wang@tum.de

Companies for home appliances often offer after-sales services, especially repair services, to their customers. One of the key challenges in this context is the planning of allocation and routing of service technicians that satisfy customers' service requests. In this paper, we consider technicians with two different skill levels. Senior technicians with extensive experience, consistently handle the repair tasks successfully, whereas junior technicians, due to their limited experience, may fail to repair the appliances, necessitating a follow-up visit by a senior technician to complete the service. Stochasticity from random service results and new customer requests are incorporated. We formulate the problem as a sequential decision problem, where decisions regarding technician allocation and routing for each workday are made, based on the information of customer requests for the upcoming workday without knowing further future demands. The objective is the minimization of the overall expected costs associated with technicians' travel and customers' waiting times. Both myopic and anticipatory methods are introduced to address the multi-period problem. We conduct a comprehensive numerical study comparing the performance of the heuristic methods under different realistic problem settings and show that the anticipatory method leads to a reduction in long-term total costs in certain settings. Additionally, we provide managerial insights into strategic allocation operations in various scenarios.

An Algorithm for Balanced and Practical Path Planning in Multi-Agent Systems

Wataru Murata[1,2], **Takahiro Suga**[1]

[1]Kawasaki Heavy Industries, Ltd., Japan; [2]Tokyo Institute of Technology, Japan; murata_wataru@global.kawasaki.com

Multi-agent path planning (MAPP) is the problem of finding an optimal set of paths for multiple agents and can be widely applied in the fleet management of different modes of mobility ranging from aircraft, ground vehicles to robots. The challenge faced in the problem lies in obtaining balanced paths for all agents when solving large-scale problems with numerous targets due to the NP-hardness. Additionally, the problem can become further complicated for the practical purpose of handling a situation where agents are expected to execute their tasks to moving targets at distant positions. To address these issues, this paper proposes a novel path planning algorithm that uses clustering and meta-heuristics. In this approach, the problem is divided into a combinatorial optimization problem of finding the target visitation orders for agents and a continuous optimization problem of determining the task execution positions of the agents. The first optimization involves clustering targets for the prioritization of agent target assignment with the aim of balancing the travel times of the agents while also accelerating the search for more promising solutions. In the second problem, our formulation allows solutions to satisfy practical constraints on the task execution with the target movements predicted. Numerical experiments conducted on simulated scenarios as well as real data examples examine the effectiveness of the proposed algorithm and demonstrate its potential for practical implementation.

Managing Equitable Contagious Disease Testing: A Mathematical Model for Resource Optimization

Peiman Ghasemi, **Jan Ehmke**

Univerdity of Vienna, Austria; peiman.ghasemi@univie.ac.at

All nations in the world were under tremendous economic and logistical strain as a result of the advent of COVID-19. Early in the epidemic, getting COVID-19 diagnostic tests was a significant difficulty. Furthermore, logistical challenges arose from the restricted transportation infrastructure and disruptions in international supply chains in the distribution of these testing kits. In the face of such obstacles, it is critical to give patients' needs top priority in order to provide fair access to testing. In order to manage contagious disease testing, this work proposes a bi-objective and multi-period mathematical model with an emphasis on mobile tester route plans and testing resource allocation. In order to optimize patient scores and reduce the likelihood of patients going untreated, the suggested team orienteering model takes into account issues like resource limitations, geographic clustering, and testing capacity limitations. To this aim, we present a comparison between quarantine and non-quarantine scenarios, introduce an equitable categorization based on disease backgrounds into “standard” and “risky” groups, and cluster geographical locations according to average age and contact rate. We use a variable neighborhood search (VNS) meta-heuristic, which has been applied for Vienna, Austria, with a case study. The results demonstrate that, over the course of several weeks, the average number of unserved risky patients in the prioritizing scenario is consistently lower than the usual number of patients. In the absence of prioritization, the average number of high-risk patients who remain untreated rises sharply and exceeds that of regular patients, though.

TA 01: GOR PhD Award

Time: Thursday, 05/Sept/2024: 8:30am - 10:00am · *Location:* Audimax
Session Chair: Jutta Geldermann

Data-driven Optimization under Uncertainty for Power Networks

Kevin-Martin Aigner

Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany; kevin-martin.aigner@fau.de

We present a comprehensive exploration of data-driven optimization under uncertainty in the context of power system analysis. Critical mathematical challenges related to the operation of power grids are addressed, accompanied by innovative solution approaches. The primary focus is on several extensions of the optimal power flow problem which is the predominantly used model in the literature to optimize the power distribution in an electricity network. We study nonconvex mixed-integer nonlinear programs arising in power system analysis, which we solve by the construction and successive refinement of piecewise linear relaxations. Our work introduces various problem-specific and generally applicable algorithmic enhancements to obtain an efficient implementation that outperforms state-of-the-art solvers. Another focus are stochastic mixed-integer linear optimal power flow problems with probabilistic constraints. The solution approach is based on the robust safe approximation of the computationally intractable chance constraints. To construct the approximative problems, suitably defined confidence sets from historical data are computed. We derive a tractable reformulation of the resulting problems and prove quality guarantees about the robustness of the calculated solutions. Numerical experiments on benchmark instances with real weather and network data demonstrate the quality of our solutions. Further improvements are achieved by combining stochastic programming with a model-based prediction of uncertainties.

On the Interplay between Data and Decisions in Discrete Location Problems

Hannah Bakker

Karlsruhe Institute of Technology, Germany; hannah.bakker@kit.edu

The Capacitated Facility Location Problem (CFLP) is a core problem in location science. We show that the combinatorial element of the MIP formulation manifests itself to different degrees in the level of interdependence between facilities serving similar subsets of customers. This induces an implied separation of the sets of candidates and customers into regions within which location decisions interdepend more strongly. Although these regions are easily identifiable in visual representations of allocation decisions or the spatial distribution of candidates and customers, detecting them solely from decision vectors is challenging. We show that spectral biclustering, a pattern recognition technique, can be used to retrieve implied regions from integer-infeasible solutions. This opens novel directions for the development of exact and heuristic solution procedures.

Dynamic Network Flows with Adaptive Route Choice based on Current Information

Lukas Graf

University of Passau, Germany; lukas.graf@uni-passau.de

Instantaneous dynamic equilibria (IDE) are an equilibrium concept for flows over time with deterministic queueing wherein individual flow particles make selfish decisions based on current information. This can be used as a model for car traffic where each driver initially chooses her route in such a way as to minimize her travel time under the current congestion state of the road network and then continuously adapts her route while driving.

We first prove existence of such equilibria under quite mild assumptions. We then show that a natural extension approach can be used to compute IDE in single-commodity networks within finite time. On the other hand we provide a multi-commodity instance where there exists a finite time horizon that cannot be reached by such an extension based algorithm within finite time. Moreover, we show that several natural decision problems involving IDE are NP-hard. Finally, we study the quality of IDE with regards to makespan as well as total travel time.

For single-commodity networks we give both upper and a lower bounds while for multi-commodity networks we provide an instance wherein IDE never terminate.

Learning Heuristics for Combinatorial Optimization Problems with Deep Neural Networks

André Hottung

Bielefeld University, Germany; andre.hottung@uni-bielefeld.de

Solving real-world combinatorial optimization problems with traditional operations research methods can be a costly and time-consuming endeavor, often requiring the development of completely new methods or significant modifications to existing techniques. In this talk, we explore several methods that use deep reinforcement learning to automate the development of problem-specific solution approaches. Rather than focusing on end-to-end solution generation, we investigate the use of machine learning to learn heuristic components for high-level search procedures. By automating the design of these components, the overall solution approach can be easily customized to the characteristics of specific problem instances, potentially lowering the barriers to entry for the use of optimization technologies across a wide range of use cases.

TA 02: Learning for Optimization 3

Time: Thursday, 05/Sept/2024: 8:30am - 10:00am · *Location:* Theresianum 0602
Session Chair: Heiko Hoppe

Accelerating Constrained Shortest Path Subproblems in Column Generation Using Machine Learning

Anne Schönhofen, Ulrich W. Thonemann

University of Cologne, Germany; anne.schoenhofen@uni-koeln.de

Column generation is an efficient algorithm for solving a variety of large-scale optimization problems. The basic idea is not to consider all variables explicitly, but to add promising variables iteratively. The problem is decomposed into a master problem and one or more subproblems that detect variables with potential for improving the current solution. In routing or scheduling applications, the subproblem is often modeled as a shortest path problem with resource constraints that is solved using a dynamic programming labeling approach. We propose a new pricing heuristic that is based on machine learning predictions. By using information collected in previous executions, labels are evaluated with respect to their probability of leading to a feasible path with negative total cost. The objective is to reduce the search space explored to accelerate the solving process. We test the method on several real-world instances of the railway crew scheduling problem provided by a major European freight railway carrier. We achieve an average reduction in the total runtime of 21% at a marginal average increase in the objective function value of 0.05% when solving the linear programming relaxation.

On Graph Neural Networks for Column Generation with Multiple Pricing Problems

Giacomo Dall'Olio[1], Yaoxin Wu[2], Rainer Kolisch[1]

[1]Technische Universität München, Germany; [2]Eindhoven University of Technology; giacomo.dallolio@tum.de

This study presents an enhancement to the Column Generation (CG) procedure for Dantzig-Wolfe decompositions featuring multiple pricing problems. CG is an efficient technique for solving large linear programs, often embedded within the branch-and-price framework to address a variety of mixed-integer linear programs. In every iteration, CG obtains new columns by solving the pricing problems and adds them to the column pool only if their reduced cost is negative, assuming a minimization problem. Our approach introduces predictions utilizing Graph Neural Networks (GNNs) to estimate the value of the reduced costs at every CG iteration. Based on these predictions, we bypass the pricing problems that we expect to yield a column with a non-negative reduced cost. To maintain the optimality of the algorithm in the case of inaccurate predictions, we solve all pricing problems at the last iteration of the CG procedure. The choice of GNNs is motivated by the graph-based nature of many pricing problems, which are challenging to handle with other architectures. We evaluate our method by integrating it into an existing approach, based on branch-and-price, used to solve an optimization problem stemming from airport operations. Our GNN models are trained on generated data and tested against real-world data. The preliminary results show promising improvements in computational time and solution quality.

Global Rewards in Multi-Agent Deep Reinforcement Learning for Autonomous Mobility on Demand Systems

Heiko Hoppe[1], Tobias Enders[1], Quentin Cappart[2], Maximilian Schiffer[1,3]

[1]School of Management, Technical University of Munich, Germany; [2]Department of Computer Engineering and Software Engineering, Polytechnique Montreal, Canada; [3]Munich Data Science Institute, Technical University of Munich, Germany; heiko.hoppe@tum.de

We study a contextual multi-stage stochastic control problem for vehicle dispatching in autonomous mobility on demand (AMoD) systems, where a central operator assigns vehicles to customer requests or rejects these with the aim of maximizing its total profit. Recent approaches use multi-agent deep reinforcement learning (MADRL) to realize scalable yet performant algorithms, but train agents based on local rewards. This distorts the reward signal with respect to the system-wide profit, leading to lower performance. We therefore propose a novel global-rewards-based MADRL algorithm for vehicle dispatching in AMoD systems, which resolves so far existing goal conflicts between the trained agents and the operator by assigning rewards to agents leveraging a counterfactual baseline. Using our novel counterfactual baseline, the algorithm combines stable learning with efficient credit assignment. Our algorithm shows statistically significant improvements across various settings on real-world data compared to state-of-the-art MADRL algorithms with local rewards. On average across test dates, our algorithm outperforms state-of-the-art local rewards-based MADRL algorithms by up to 2%, which translates into daily monetary savings of several ten thousand euros from an operator's perspective. On single test dates, it outperforms them by up to 6%. At the same time, it has better scalability properties with regards to the instance size than any other tested global rewards-based algorithm, being as scalable as purely local rewards-based MADRL algorithms. We further provide a structural analysis which shows that the utilization of global rewards can improve implicit vehicle rebalancing and demand forecasting abilities.

TA 03: Explainability and Interpretability 1

Time: Thursday, 05/Sept/2024: 8:30am - 10:00am · *Location:* Theresianum 0606
Session Chair: Kevin Tierney

Explainability and Interpretability in Mathematical Optimization

Michael Hartisch

Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany; michael.hartisch@fau.de

The evolution of mathematical programming has revolutionized our ability to address once-deemed intractable real-world problems on a large scale. Despite the efficiency of modern optimization techniques, the reluctance to accept provably optimal solutions persists, largely attributed to the perception of optimization software as a black box by many stakeholders. While well-understood by the scientific community, this lack of transparency poses a barrier to practitioners. We advocate for a paradigm shift by emphasizing the importance of incorporating aspects of interpretability and explainability in mathematical optimization. By clarifying the concepts of explainability and interpretability, we aim to bridge the gap between the advanced techniques understood by scientists and the accessibility required by practitioners. We will showcase initial steps taken in this direction and engage in a discussion on potential future directions.

Learning to solve combinatorial optimization problems with a decision tree

Kevin Tierney

Bielefeld University, Germany; kevin.tierney@uni-bielefeld.de

Deep reinforcement learning has made incredible strides in solving combinatorial optimization problems (COPs) and nearly outperforms the current state-of-the-art OR heuristics on several problems. However, a key drawback of deep neural network approaches is that they are not interpretable, that is, it is essentially impossible to understand how they actually solve optimization problems. To this end, I introduce a fully interpretable mechanism for generating interpretable models for solving COPs using a decision tree. The method harnesses a pairwise ranking mechanism to construct solutions, thus allowing it to learn to solve various instance sizes with a single model. To train the decision tree, I introduce an end-to-end learning technique to generate trees that are customized to specific datasets and show the effectiveness of this technique experimentally on several COPs.

Explainable Mathematical Optimization with Feature Selection

Kevin-Martin Aigner[1], Marc Goerigk[2], Michael Hartisch[1], Frauke Liers[1], Arthur Miehlich[1], Florian Rösel[1]

[1]Friedrich-Alexander Universität Nürnberg-Erlangen, Germany; [2]Universität Passau, Germany; arthur.miehlich@fau.de

Mathematical optimization is a powerful tool to increase the efficiency of various business processes. Nevertheless, its potential is often not fully exploited. Especially, if practitioners do not have trust in the superiority of optimized solutions, they have little chance to be implemented. Our approach to increase trust in optimized solutions is to justify them by providing a sample of similar solutions found for similar problem instances in the past that have actually been implemented and proved themselves efficient. This method raises the question what "similar" in terms of instances or solutions actually means. This paper addresses hence the challenge of establishing a similarity measure among problem instances within a dataset in order to foster consistency in the solution space. The primary objective is to identify features from a predefined set that induce similar instances to produce similar solutions. The methodology employs a feature extraction process formulated as a Mixed Integer Programming model, which is tailored to capture the inherent characteristics that govern solution coherence across similar instances. To mitigate complexity, we employ conventional AI concepts, such as batch learning, in a customized manner. Empirical evaluation across diverse datasets demonstrates the effectiveness of our feature-selection approach in enhancing solution consistency and facilitating explainability within real-world problem-solving contexts.

TA 04: Applications of Stochastic Optimization

Time: Thursday, 05/Sept/2024: 8:30am - 10:00am · *Location:* Wienandsbau 2999
Session Chair: Baruch Keren

Solution Approaches for a Stochastic Lot Sizing Problem with Limited Inventory

Duygu Tas[1,2]
[1]Faculty of Engineering and Natural Sciences, Sabancı University; [2]Smart Mobility and Logistics Lab, Sabancı University;
duygu.tas@sabanciuniv.edu

In this study, we focus on a capacitated lot sizing problem (CLSP) with stochastic times and limited inventory. The classical CLSP aims to minimize the total cost including the costs of production, setup and inventory, and to meet the demands using a single machine. This machine can produce several different items in each time period, where its capacity is consumed both by production and by setup operations. In real-life applications, uncertainties, especially the ones in production and setup times, are real concerns for companies. To obtain efficient production plans to be performed in real-life environment, we consider stochastic setup and production times following a given probability distribution. In this setting, overtime costs are incurred in case the machine is used beyond its production capacity. The proposed problem also addresses the limited storage space of the warehouses. More specifically, the level of the inventory at the end of each time period is assumed to be bounded to better reflect the real-life applications in which warehouses with limited storage areas are mostly used to store several different items. The problem described above is formulated as a stochastic programming with recourse (overtime) decisions. Two approximate solution approaches are developed. The first approach is based on the tabu search method, whereas the second approach is based on solving the stochastic programming with a set of sample scenarios. The computational experiments are conducted on well-known problem instances and extensive analyses are provided.

Adressing Inventory Planning Challenges with Stochastic Optimization: A Comprehensive Study

Sarah Neumann, Laura Brouer, Christoph Hölck
Fraunhofer IIS, Germany; sarah.neumann@iis.fraunhofer.de

Uncertainties in demand and supply dynamics pose significant challenges to inventory planning, often leading to inefficiencies and increased costs. Traditional approaches tend to fall short in effectively addressing these challenges by accommodating fluctuations in demand. To address this issue, we propose and evaluate a novel approach utilizing a stochastic mathematical optimization model.

The key outcome is the development and implementation of a mathematical optimization model which is specifically designed to address the complexities of inventory planning by incorporating uncertainties in demand and other relevant factors such as lead times, storage constraints and purchasing costs. Furthermore, an extensive evaluation study is conducted to assess the performance of the proposed model. Various key performance indicators (KPIs) like purchasing costs, stock level and service level are analyzed to compare the effectiveness of the derived purchasing strategy with alternative approaches. Through this evaluation, insights into the model's ability to mitigate inventory-related challenges and improve operational efficiency are gained. Additionally, the study investigates the impact of parameter values, providing valuable insights into optimizing decision-making processes.

In conclusion, this study presents a comprehensive solution to the challenges of inventory planning through the development and implementation of a stochastic optimization model. By addressing uncertainties in demand and conducting a thorough evaluation of different strategies and parameters, the study contributes to improving inventory management practices and enhancing supply chain performance and resilience.

Optimal Budget Allocation for Project Risk Mitigation Using Monte Carlo Simulation and Mathematical Programming

Baruch Keren, Yossi Hadad
SCE – Shamoon College of Engineering, Israel; baruchke@sce.ac.il

This presentation presents a method for optimally allocating a limited budget to mitigate project risks. After identifying the project risks, the project manager must prioritize which risks to address. The challenge lies in the fact that the occurrence of these risks, their impacts on the project's cost, schedule, and quality/content, and even the outcomes of the risk response plan can all be random variables. The proposed method begins with a Monte Carlo simulation to model the risk impacts and the residual effects after implementing the risk responses. The simulation results serve as inputs to mathematical programming methods, which determine the optimal budget allocation among the risks, considering various objective functions.

TA 05: New Approaches to Optimization under Uncertainty

Time: Thursday, 05/Sept/2024: 8:30am - 10:00am · *Location:* Wienandsbau 3999
Session Chair: ALBAN KRYEZIU

Using the R* criterion to selected optimization problems under uncertainty

Romain Guillaume[1], Adam Kasperski[2], Szymon Michał Wróbel[2], Paweł Zieliński[2]
[1]Universit\'e de Toulouse-IRIT, France; [2]Wrocław University of Science and Technology, Poland; szymon.wrobel@pwr.edu.pl

In robust optimization, the impact of uncertainty is typically modeled using the min-max approach, where the goal is to optimize the solution cost under a worst-case scenario. This approach does not take into account good scenarios that can occur and may lead to very conservative solutions.

The R* uninorm is an aggregation operator that selects the minimal value when all arguments are below a selected threshold and the maximal value otherwise. Its axiomatic characterization, applications to decision-making, and comparison to the traditional Hurwicz criterion were provided by Fargier and Guillaume in 2019. The main goal of this paper is to present an application of the R* approach to optimization problems under uncertainty. The framework is based on a threshold value: we seek an optimistic solution (we solve the min-min problem) under the assumption that its maximum cost does not exceed the threshold; if no such solution exists, then we go back to optimizing the solution cost in a worst case (we solve the traditional min-max problem).

The R* approach is applied to some basic optimization problems such as selection or shortest path, under various uncertainty representations. The computational complexity of the problem is investigated and some methods of solving it are proposed.

Multilevel Conditional Compositional Optimization

Buse Sen[1], Daniel Kuhn[1], Yifan Hu[1,2]
[1]EPFL, Switzerland; [2]ETH, Zurich, Switzerland; buse.sen@epfl.ch

We introduce Multilevel Conditional Compositional Optimization (MCCO) as a new framework for decision-making under uncertainty that extends conditional stochastic optimization (CSO). MCCO minimizes a nest of conditional expectations and nonlinear cost functions. It finds wide applications in optimal stopping, credit valuation adjustments, distributionally robust contextual bandits, nested risk minimization, and federated CSO. The naive nested sampling approach for MCCO suffers from a curse of dimensionality, that is, its sample complexity grows exponentially with the number of nests. We develop new multilevel Monte Carlo techniques for MCCO whose sample complexity grows only polynomially with the desired accuracy.

Vitali variation error bounds for expected value functions

ALBAN KRYEZIU
University of Groningen, Netherlands, The; a.kryeziu@rug.nl

In this paper we derive error bounds for one and two-dimensional expected value functions that depend on the Vitali variation of the joint probability density function of the corresponding random vector. Contrary to bounds from the literature, our bounds are not restricted to underlying functions that are one-dimensional and periodic. Moreover, we show that our new bounds are tighter when the components of the random vector are independent and have marginal densities with total variation less than one. In our proof, we first derive the bounds in a discrete setting, where we show that the extreme points in this setting are the set of all matrices that have zero-sum rows and columns and have an L_1-norm bounded by one. This result may be of independent interest. Finally, we numerically illustrate the performance of our new bounds by applying them to convex approximations of stochastic integer programs from the literature.

TA 06: Applications of Combinatorial Optimization 1

Time: Thursday, 05/Sept/2024: 8:30am - 10:00am · *Location:* Wirtschaftswissenschaften Z534
Session Chair: Marc Gennat

Optimizing Referee Assignments in North Rhine-Westphalia's American Football Leagues

Michael Dienstknecht

University of Groningen, Netherlands, The; m.dienstknecht@rug.nl

In sports, two key planning challenges are the scheduling of games / matches and the assignment of officiating staff to such games / matches. Addressing any of these usually requires accounting for very specific characteristics of, e.g., the sport, the level of play or the mode of competition. Consequently, decision support tools need to be tailored to these requirements rather than allowing for a one-size-fits-all solution.

This research is dedicated to the problem of assigning officiating crews to American football games in North Rhine-Westphalia (NRW), Germany. An amateur league system in terms of both competition and officiating, there are several hundred games per season in need of officiating crews that have to meet certain league-dependent requirements while accounting for each official's availability.

Being out of reach for exact approaches, two heuristic algorithms – an adaptive large neighborhood search and a mixed-integer programming-based decomposition procedure – are proposed to tackle the problem and support the planning authorities who primarily rely on expert knowledge at this point.

Computational tests on real-world instances demonstrate substantial improvements over said expert solutions for both heuristics.

Balancing accessibility and fairness: Optimally closing recycling centers in Bavaria

Malena Schmidt[1], Christian Schmitt[2], Bismark Singh[3]

[1]Delft University of Technology (TU Delft), Netherlands; [2]Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany; [3]University of Southampton, United Kingdom; b.singh@southampton.ac.uk

Typically, within facility location problems, fairness is defined in terms of accessibility of users. However, for facilities perceived as undesirable by communities hosting them - such as recycling centers - fairness between the usage of facilities becomes especially important. We develop a series of optimization models for the allocation of populations of users to such recycling centers such that access for users is balanced with a fair utilization of facilities. The optimality conditions of the underlying nonconvex quadratic models state the precise balance between accessibility and fairness. We define new classes of fairness and a metric to quantify the extent to which fairness is achieved in both optimal and suboptimal allocations.

Within the state of Bavaria in Germany, such centers have closed in the last few decades. Using mobility survey data we show how selective closures of these centers can still lead to high levels of recycling access. Our analysis ensures that even when 20% of facilities are closed smartly, the median travel distance by residents to their assigned recycling center increases by only 450 m. Additionally, we find Bavaria suffers from disparity in recycling patterns in rural and urban regions, both in terms of motivation to recycle and the locations of the facilities. We promote a policy that favors retention of recycling centers in rural regions by reserving 75% of open facilities to be in rural areas, while selectively closing facilities in urban regions, to remove these regional differences.

This work is based on two recently published articles.

Allocation of Students to Laboratory Groups Taking Into Account Constraints from Timetables and Student Availabilities at Niederrhein University of Applied Sciences

Marc Gennat

Hochschule Niederrhein University of Applied Sciences, Germany; marc.gennat@hs-niederrhein.de

Organizing lab groups in a University of Applied Sciences is a challenging task that is often done by manually assigning students to groups. For sufficiently large cohorts of students, the optimal allocation is often not reached, which is achieved by minimizing the teaching effort of instructors and minimizing the occupancy of laboratories.

In this contribution, an integer programming approach is employed to allocate students to lab groups across the Faculty of Mechanical Engineering, while minimizing the total number of groups needed. The algorithm particularly addresses the challenge of the availability of professors and laboratories, aligning the availability of students from four different bachelor programs with their personal preferences for certain weekdays, which they provide in advance. Additionally, the flexibility or restrictions required by part-time and dual study programs in terms of lab participation are integrated into the model.

The developed algorithm uses an iterative procedure that checks all relevant constraints in each iteration using IP. If the constraints lead to an infeasible solution, the less important constraints are dropped until a feasible solution is found. The choice of an objective function ensures minimal teaching effort and lab usage, but does not take advantage of group sizes. In a second iterative process, all group sizes are equalized as long as the problem is feasible.

The example computes 862 lab group assignments with a solution vector of 32,344 components, 7944 inequalities and 346 equality constraints to model the lab group assignment.

TA 07: Theory of Combinatorial Optimization 1

Time: Thursday, 05/Sept/2024: 8:30am - 10:00am · *Location:* Wirtschaftswissenschaften Z536
Session Chair: Sven de Vries

The n-queens problem in higher dimensions

Tim Kunt

Zuse Institute Berlin, Germany; kunt@zib.de

How many mutually non-attacking queens can be placed on a d-dimensional chessboard of size n? The n-queens problem in higher dimensions is a generalization of the well-known n-queens problem. We provide a comprehensive overview of theoretical results, bounds, solution methods, and the interconnectivity of the problem within topics of discrete optimization and combinatorics. We present an integer programming formulation of the n-queens problem in higher dimensions and several strengthenings through additional valid inequalities. Compared to recent benchmarks, we achieve a speedup in computational time between 15-70x over all instances of the integer programs. Our computational results prove optimality of certificates for several large instances. Breaking additional, previously unsolved instances with the proposed methods is likely possible. On the primal side, we further discuss heuristic approaches to constructing solutions that turn out to be optimal when compared to the IP. We conclude with preliminary results on the number and density of the solutions.

Recoverable Robust Cardinality Constrained Maximization of a Submodular Function

Sabine Münch, Stephen Raach, Sven de Vries

Trier University, Germany; muench@uni-trier.de

We consider a game-theoretic variant of maximizing a non-decreasing submodular function under a cardinality constraint. Initially, a solution to this classical problem is determined. Subsequently, a predetermined number of elements from the ground set, not necessarily contained in the initial solution, are deleted, potentially reducing the solution's cardinality. Afterwards, the current solution is expanded by adding available elements, adhering to the cardinality constraint. The objective is to maximize the value of the ultimate solution, with the deletion being maximally disadvantageous to the initial solution.

For M-natural-concave objective functions and any predetermined number of deleted elements, we show that the greedy algorithm returns an optimal solution. Assuming the deletion of exactly one element, we introduce an algorithm that yields an ultimate solution approximating the optimal ultimate solution to this problem by at least 0.5(1-1/e).

On Inner Independence Systems

Sven de Vries[1], Stephen Raach[1], Rakesh V. Vohra[2]

[1]Trier University, Germany; [2]University of Pennsylvania, PA, USA; devries@uni-trier.de

A classic result of Korte and Hausmann (1978) and Jenkyns (1976) bounds the quality of the greedy solution to the problem of finding a maximum value basis of an independence system (E,I) in terms of the rank-quotient.

We extend this result in two ways. First, we apply the greedy algorithm to an inner independence system contained in I. Additionally, following an idea of Milgrom (2017),

we incorporate exogenously given prior information about the set of likely candidates for an optimal basis in terms of a set. We provide a generalization of the rank-quotient that yields a tight bound on the worst-case performance of the greedy algorithm applied to the inner independence system relative to the optimal solution in O. Furthermore, we show that for a worst-case objective, the inner independence system approximation may outperform not only the standard greedy algorithm but also the inner matroid approximation.

Second, we generalize the inner approximation framework of independence systems to inner approximations of packing instances by inner polymatroids and inner packing instances. We consider the problem of maximizing a separable discrete concave function and show that our inner approximation can be better than the greedy algorithm applied to the original packing instance. Our result provides a lower bound to the generalized rank-quotient of a greedy algorithm to the optimal solution in this more general setting and subsumes Malinov and Kovalyov (1980). We apply the inner approximation approach to packing instances induced by the FCC incentive auction and by two knapsack constraints.

TA 08: Optimal Control Applications

Time: Thursday, 05/Sept/2024: 8:30am - 10:00am · *Location:* Wirtschaftswissenschaften Z538
Session Chair: Gustav Feichtinger

Analyzing the Impact of Advertising on Manufacturer-Retailer Business Model Choice in Bilateral Monopoly

Sigué Simon[1], Gromova Ekaterina[2]

[1]Athabasca University; [2]Transport and Telecommunication Institute (TSI); gromova.e@tsi.lv

This study explores how advertising influences manufacturers' and retailers' decisions between reselling and agency selling in bilateral monopolies. Three analytical models examine under what conditions each strategy is admissible. The Stackelberg equilibrium is analytically derived for all models, delivering the optimal solution, and explaining the structure of strategic interactions. Managerially, the importance of considering advertising's impact on consumer demand when selecting a business model is highlighted.

In this research, we mostly have focused on vertical pricing and advertising interactions in a context where a manufacturer sells a single product to a retailer or to consumers via a retailer-owned platform. Additionally, preliminary findings will be presented on using different channel structures, including horizontal competition.

Optimal Paths to Demographic Equilibria

Stefan Wrzaczek[1], Thomas Fent[2], Gustav Feichtinger[3], Andreas J. NOVAK[4]

[1]IIASA; [2]Austrian Academy of Sciences; [3]Vienna University of Technology; [4]University of Vienna; andreas.novak@univie.ac.at

The principle goal of the presentation is to establish a firm fundament of population policy. It is shown how intertemporal optimisation theory can be used to fulfill this important task. In particular this will be illustrated by calculating the optimal trade-off between the further growth (or shrinking) of a population and the fluctuations of its age-structure generated by the decline (or increase) of the fertility.

While the system dynamics of the age-structured optimal control model considered in this paper is described by the McKendrick-von Foerster partial differential equation, its objective functional is given by the discounted stream of the adaptation costs of the net reproduction rate (NRR) and the afore-mentioned trade-off. Numerical simulations for a stylized population structure show how the change of the NRR carries over to the total population and age groups along time.

How to control Mexican cartels in an optimal way?

Gustav Feichtinger[1], Gian Maria Campedelli[2], Jonathan P. Caulkins[3], Dieter Grass[1], Rafael Prieto-Curiel[4], Gernot Tragler[1], Stefan Wrzaczek[5]

[1]TU Wien, Austria; [2]Fondazione Bruno Kessler, Italy; [3]H. John Heinz III School of Public Policy & Management, Carnegie Mellon University, USA; [4]Complexity Science Hub, Austria; [5]Economic Frontiers, Institute for Applied Systems Analysis (IIASA), Austria; gustav.feichtinger@tuwien.ac.at

Violence is today one of the most serious issues in most Latin American countries. State forces in Mexico invest considerable resources to reduce homicides. Essentially, two instruments are available to control the power of cartels, namely incapacitation of its members and reducing recruitment.

In a remarkable recent paper (Prieto-Curiel et al., Science 381, 1312–1316, 2023), two of the above authors have shown that 'reducing cartel recruitment is the preferred way to lower violence in Mexico'. It seems to be natural to ask additionally how the control instruments should be varied optimally over time. To answer this question we have to quantify the impact of incarceration and recruitment reduction on the dynamics of the cartel sizes. Or, to put in another way, one has to specify the costs of the controls restricted by the available budget of the Mexican government. In that context the validation of the proposed control model is a crucial step to obtain not only interesting insights into the structure of efficient incapacitation and recruitment policies but (hopefully) also policy recommendations.

Preliminary calculations for two interacting cartels show that for realistic parameter constellations multiple long-run optimal equilibria do exist. Their basins of attraction are separated by Skiba-curves implying history-dependence of the optimal solutions.

TA 09: Assortment Planning

Time: Thursday, 05/Sept/2024: 8:30am - 10:00am · *Location:* Wirtschaftswissenschaften Z532
Session Chair: Robert Klein

Stochastic dynamic assortment optimization with replenishment and decreasing product revenues

Julia Heger[1,2], Robert Klein[2]

[1]BMW AG, Germany; [2]Universität Augsburg, Germany; julia.heger@uni-a.de

We study the dynamic retail assortment problem with two sources of stochasticity. In particular, we consider stochasticity in terms of the products purchased by the customers, and in terms of replenishment, i.e., stochasticity regarding the newly incoming products. In addition, we account for the fact that the products suffer a loss in value over time, whereby we compare multiple different types of value loss functions. The considered setting is motivated by a joint project with the German car manufacturer BMW. We formulate the stochastic dynamic assortment problem as dynamic program and prove it to be NP-hard. Since the stochastic dynamic programming algorithm is intractable for instances of medium to large size in our setting, we additionally propose a heuristic solution approach that is based on the idea of solving the static problem per period using some base policy as well as an approximate dynamic programming based solution approach called Truncated Stochastic Rollout. We conduct extensive numerical studies to compare the proposed solution approaches for various base policies and obtain managerial insights regarding the choice of the most suitable value loss function.

Assortment Optimization Under the Nested Logit Model with Customer Segments

Stefan Rogosinski[1], David Sahya[2], Sven Müller[1]

[1]RWTH Aachen University, Germany; [2]Forschungszentrum Informatik FZI, Germany; mueller@analytics.rwth-aachen.de

We propose a new problem to the assortment optimization literature: the (constrained) assortment problem under the nested logit model with heterogeneous customers. So far, only nested logit models with homogenous customers are considered (i.e., each customer evaluates the assortment similarly). In contrast, empirical nested logit product choice models almost always consider customer characteristics like income, age, and location, for example. We account for this heterogeneity in our new problem and show that the resulting problem is (i) NP-hard, (ii) non-linear, and (iii) non-convex. However, we present a MIP reformulation based on a piece-wise linearization that yields a (1+e)/(1-e) approximation. We develop a lower bound for the number of breakpoints for the piece-wise linearization given an arbitrary e. First numerical studies show promising results.

Assortment Planning and Pricing with Consumer Searching: The Role of Anticipated Regret

Ruibing Wang, Cornelia Schön, Oliver Vetter

University of Mannheim, Germany; ruibing.wang@uni-mannheim.de

Consumers often search for product information to resolve valuation uncertainties before purchasing. Since they cannot examine all alternatives because of their limited information-acquisition ability, they conduct a two-stage search, called consider-then-choose. In the first stage, they decide a consideration set which is a subset of all available alternatives, In the second stage, they resolve the uncertainty about all products in this consideration set and choose the one with the highest utility. We extend assortment optimization under consumer choice behavior by incorporating consumer anticipated regret into the consideration set formation. Specifically, after purchase, when consumers passively notice whether an unconsidered product is more suitable than the purchased one or not, they might regret having decided a small consideration set and not devoted enough effort to searching or regret having decided a large consideration set and devoted too much effort to searching. We show that if consumers anticipate the post-purchase regret when deciding a consideration set, in some conditions the firms should offer some products that consumers will not consider. Based on this finding, we develop fully-polynomial approximation schemes or exact conic formulation for a variety of assortment problems under the consider-then-choose models with anticipated regret. For the joint assortment planning and pricing problem with homogeneous consumers, we show that the intrinsic-utility ordered assortment and the price policy that charges the same price for the products except at most those outside the consideration set and one within it are optimal.

TA 10: Medical Decision Support

Time: Thursday, 05/Sept/2024: 8:30am - 10:00am · *Location:* Wirtschaftswissenschaften 0514
Session Chair: Nico van Dijk

Decision Diagram Optimization for Allocating Patients to Medical Diagnosis

Aru Suzuki[1], Ken Kobayashi[1], Kazuhide Nakata[1], Yuta Kurume[2], Naoyuki Sawasaki[2], Yuki Sasamoto[2]

[1]Tokyo Institute of Technology, Japan; [2]Fujitsu Limited, Japan; suzuki.a.bh@m.titech.ac.jp

In Japan, due to the shortage of healthcare workers, there has been a growing need to effectively allocate patients to different medical diagnoses or treatments according to the severity of their illness and the capabilities of medical institutions. However, since these rules have often been created manually by Japanese local municipalities, whether the resulting rule is reasonable is unclear, and creating a rule requires a lot of effort. In this talk, we propose a data-driven approach for designing a patient allocation rule for medical diagnoses. Since patient allocation rules can be expressed as a flowchart-style diagram, our task of designing an allocation rule is similar to a machine-learning problem of tree-based classification models. Due to its modeling capabilities, mixed-integer optimization has recently attracted attention for learning such tree-based models. Thus, we propose a mixed-integer optimization approach to obtain an effective decision diagram for allocating patients to medical diagnoses with practical constraints on medical resources. Specifically, this study focuses on chronic kidney disease (CKD) and allocating patients into three diagnostic classes: "See a diabetologist," "See a nephrologist," and "Do nothing." We first show that the current allocation rules can be summarized as a decision diagram. We then introduce practical constraints to consider (e.g., healthcare institutions' capacity or medical cost constraints). Finally, we give a mixed-integer optimization formulation to find a decision diagram with high diagnosis effects and low medical costs. Our numerical experiments with synthetic data demonstrated that the proposed method could provide effective medical diagnosis allocations at a low cost.

Optimal vaccination in the presence of waning immunity - an immuno-epidemiological model

Raimund Kovacevic[1], Georgi Angelov[1], Nikolaos Stilianakis[3], Vladimir Veliov[2]

[1]University for Continuing Education, Krems, Austria; [2]Vienna University of Technology, Vienna, Austria; [3]European Commission, Joint Research Centre (JRC), Ispra, Italy; raimund.kovacevic@donau-uni.ac.at

In epidemics, waning immunity is common after infection or vaccination of individuals. Immunity levels are highly heterogeneous and dynamic. This work presents an immuno-epidemiological model that captures the fundamental dynamic features of immunity acquisition and wane after infection or vaccination and analyzes mathematically its dynamical properties. The model consists of a system of first order partial differential equations, involving nonlinear integral terms and different transfer velocities. Structurally, the equation may be interpreted as a Fokker-Planck equation for a piecewise deterministic process. However, unlike the usual models, our equation involves nonlocal effects, representing the infectivity of the whole environment. In addition, the asymptotic behavior of the model is analyzed based on the obtained qualitative properties of the solution.Finally, an optimal control problem with objective function including the total number of deaths and costs of vaccination is explored, with applications in public health in view.

An Erlang Loss bound for Finite Tandem Queues with Intensive–Medium Care Application

Nico van Dijk, Yufan Cui

University of Amsterdam, The Netherlands; nicomvandijk@gmail.com

Abstract

An Intensive Care Unit – Medium Care Unit (IC-MC) system in a hospital can be regarded as a finite tandem queue with a finite Intensive Care (ICU) and a finite Medium Care unit (MCU) (also known as Step-Down Unit). Finite tandem queues are known to be widely applicable but also hard to solve analytically. Particularly by the Covid-19 pandemic it revived as of societal and solvability interest.

An ICU patient standardly needs to pass both stages for recovery and observation. A key-indicator to evaluate the performance of this system is the ICU congestion probability. The presentation aims to highlight:

• a first-order if not reasonably accurate bound by a simple Erlang loss expression

• numerical support and an IC-MC application

• a formal proof as a lower bound.

The Erlang bound seems trivial. Yet counter-intuitive examples at sample path basis are easily constructed. For the average case a technical formal proof can be given related to Markov Dynamic Programming (MDP). Numerical support is provided for natural IC-MC situations. These also capture nón-exponential (realistically: lognormal) recovery times. Accordingly, it might well be practical for real-life IC-MC dimensioning.

TA 11: Markets

Time: Thursday, 05/Sept/2024: 8:30am - 10:00am · *Location:* Theresianum 2609
Session Chair: Reinhard Neck

Convergece of Adaptive Pricing Algorithms in Two-Sided Markets

Janik Bürgermeister, Martin Bichler, Maximilian Schiffer

Technical University Munich (TUM), Germany; janik.buergermeister@tum.de

Pricing on two-sided markets such as AirBnB or Uber is typically automated via learning algorithms that adapt to changes in demand and supply. This paper investigates the convergence of deep reinforcement learning (DRL) algorithms towards equilibrium prices in two-sided markets, building on the foundational platform model introduced by Armstrong. We begin by establishing that the pricing game in two-sided markets is strictly monotonous, which proves the convergence of projection algorithms to an equilibrium. These results do not extend to DRL, which is more challenging to analyze theoretically due to their use of neural networks. In extensive experiments, we demonstrate that popular DRL algorithms such as Proximal Policy Optimization (PPO) and REINFORCE reliably converge to price equilibria in these markets as well. Our findings are significant in light of recent concerns regarding algorithmic collusion by AI-driven pricing agents in traditional oligopoly models. Contrary to fears raised by studies in these markets, our results suggest that such phenomena are less of a concern in two-sided market structures.

Dynamic Game Models of Macroeconomic Policies for a Monetary Union

Reinhard Neck

University of Klagenfurt, Austria; reinhard.neck@aau.at

In this paper we give a brief introduction to dynamic games and their applications to problems of macroeconomic policy. Then we present an application of the dynamic tracking games framework to modeling a monetary union. We use a small stylized nonlinear two-country macroeconomic model of a monetary union to analyze the interactions between fiscal (governments) and monetary (common central bank) policy makers, assuming different objective functions of these decision makers. Using the OPTGAME algorithm for the numerical approximate solution of these games, we study the impacts of an exogenous fall in aggregate demand and the resulting increase in public debt, similar to the economic crisis (2007–2010) and the sovereign debt crisis (since 2010) in Europe. In the union, the governments of participat-ing countries pursue national goals when deciding on fiscal policies whereas the common central bank's monetary policy aims at union-wide objective variables. The union considered is asymmetric, consisting of a "core" with lower initial public debt, and a "periphery" with higher initial public debt. We analyze several possible solutions to deal with these crises within the dynamic game model under consideration.

TA 12: MCDM in Transportation and Supply Networks

Time: Thursday, 05/Sept/2024: 8:30am - 10:00am · *Location:* Theresianum 2601
Session Chair: Moritz Link

Flexible selection of Pareto-optimal solutions in the context of multimodal mobility

Lara Schneider, Julia Rieck
University of Hildesheim, Germany; schneider@bwl.uni-hildesheim.de

Nowadays, travelers can choose from an increasing variety of mobility services to reach their desired destination. Manually researching and comparing various offers involves a great deal of personal effort, which is why suitable decision support is required. The aim is to suggest a personalized selection of routes to travelers, whereby the selection strategy should consider several aspects: Depending on the personal weighting of criteria such as, e.g., arrival time, distance, costs, emissions, or number of transfers, different people may prefer different options. Furthermore, due to the multimodal nature of the problem, where various transportation options can lead to equal objective function values, it is relevant to include the available variety of transportation combinations.

The problem is formulated as a many-objective scenario-based model, for which at first the Pareto set for up to five preferences is determined using an approximation approach. Afterwards, a flexible, traveler-friendly number of Pareto-optimal solutions is selected, which adequately represent the variety of available offers by taking into account the diversity found in the objective as well as the decision space. The selection process is guided by travelers' self-assessed preference weightings, which, according to studies, do not accurately reflect their real-life actions and can only be considered as an indication.

The new selection strategy is tested on the multimodal network of the city of Hildesheim. Preliminary results show the effective reduction of the Pareto set to a suitable number of solutions, which concisely informs the traveler about reasonable alternatives and enables him to make an appropriate choice.

A pareto local search approach for using the load flexibility in smart districts

Thomas Dengiz
Karlsruhe Institute of Technology, Germany; thomas.dengiz@kit.edu

To cope with the fluctuating electricity generation by renewable energy sources and decarbonize the building sector, flexible electrical loads like electric vehicles or electric heating devices are necessary. As the building sector is a major emitter of greenhouse gas emissions, with the majority caused by the provision of heat, there is an increased need for optimal control of heating systems in buildings. In this paper, multi-objective optimization problems for the control of heating systems and electric vehicles are defined for typical German residential districts. Since different, partly conflicting objectives arise in residential areas (energy costs, CO2-emissions, peak loads grid, thermal comfort, etc.), we use approaches from the field of multi-objective optimization.

Next to exact methods for solving multi-objective optimization problems like the dichotomic method, we introduce a novel pareto local search method for controlling heat pumps. The goal is to minimize the energy costs and to maximize the inhabitant's thermal comfort while not creating additional peak loads in the grid. The local search approach starts from a naive solution and iteratively tries to improve the solutions by searching for better feasible heating schedules in the neighborhood of the original solution.

We compare the approach to metaheuristics for multi-objective optimization like the evolutionary algorithm NSGA-II and to conventional control strategies, like the hysteresis control.

Integrating homeowner acceptance of retrofit measures into multi-objective energy supply network optimization

Carl Eggen, Moritz Link, Stefan Volkwein
Universität Konstanz, Germany; moritz.link@uni-konstanz.de

In light of the ongoing developments in the climate crisis, it is necessary to consider factors beyond the sole economic perspective in energy supply network planning. In this talk, we propose a modeling framework allowing for a three-pronged approach: besides minimizing the network costs, we additionally aim for lowering the network's carbon emissions as well as the homeowner buy-in for energy-efficiency retrofit measures. While the former two are widespread aspects when optimizing energy supply networks, the latter is a rather untouched one – yet, a successful transformation towards a low carbon energy supply crucially depends on the homeowner acceptance. Following a short introduction of the

underlying model, we introduce the notions necessary for integrating homeowner acceptance yielding a multi-objective optimization problem. We conclude the talk by highlighting some mathematical aspects together with presenting some numerical results.

TA 13: Solver Interfaces

Time: Thursday, 05/Sept/2024: 8:30am - 10:00am · *Location:* Theresianum 2605
Session Chair: Daniel Junglas

Automatic Reformulations in AMPL's New MP Solver Interface Library

Jurgen Lentz, Filipe Brandão, Christian Valente
AMPL Optimization Inc., USA; jurgen.lentz@rwth-aachen.de

MP is AMPL's new solver interface library. It streamlines iterative model development by offering automatic model reformulations. These include model decompositions (e.g., linearization of logical constraints), model globalization (e.g., filtering of conic constraints), as well as piecewise-linear approximation. Tools are offered to explore reformulations performed on a model. The library also streamlines solver interface development via a flexible type-safe C++ class hierarchy.

Automatic reformulations, performed either by a modeling tool or in the solver, can sometimes hide numerical issues with a solution. We discuss examples and workarounds.

New solver drivers built with this interface include Gurobi, CPLEX, Xpress, COPT, MOSEK, HiGHS, CBC, SCIP, and GCG.

AMPLS Libraries for Flexible and Advanced Algorithm Implementation

Christian Valente, Filipe Brandão, Jurgen Lentz
AMPL Optimization, United States of America; ccv@ampl.com

AMPLS Solver Libraries allow users to seamlessly export AMPL model instances to persistent solver representations, facilitating advanced solution algorithm implementation. Compatible with C++, Python and C#, these libraries offer flexibility in terms of performance/ease of use tradeoff.

The libraries ensure a smooth transition from AMPL modeling to ad-hoc algorithm implementation. Notably, some solver functionalities are mapped to allow the reuse of implementations across solvers, while retaining access to solver-specific features. This mapping streamlines the development process, providing a unified interface for common functionalities while preserving the unique capabilities of each solver.

Writing and solving models with the augmented FICO Xpress Solver APIs

Daniel Junglas
FICO, Germany; danieljunglas@fico.com

FICO Xpress 9.4 introduced a brand-new programming API for building and solving optimization problems in Java and C# using the Xpress Solver. The new FICO Xpress Solver API for Java and C# is designed as an object-based layer ensuring a memory-efficient and reliable experience for the user.

With the new API, the use of Solver features such as callbacks becomes easier, and it gives access to the full set of problem types available with Xpress Solver.

Among the key features of the new Xpress Solver API are the ability to use modern programming concepts such as Collections, Streams, Lambdas, and operator overloading to build expressions and constraints.

The new Solver API offers seamless integration with the Solver and access to cutting-edge features. We observed model building times speedup by a factor of 8 on models with several millions of variables and constraints compared to previous APIs.

We will present this new API and will also explore other ways to create and solve optimization problems using FICO Xpress Optimizer in different programming languages.

TA 14: Optimization in Construction and Additive Manufacturing

Time: Thursday, 05/Sept/2024: 8:30am - 10:00am · *Location:* Theresianum 2607
Session Chair: Mehdi Sharifyazdi

3D Roof Reconstruction with a Mixed Integer Linear Program

Steffen Goebbels, Jochen Rethmann
Hochschule Niederrhein, iPattern-Institut, Germany; steffen.goebbels@hsnr.de

Many of the 3D city models offered by the German federal states were created using a model-driven approach based on airborne laser scanning point clouds. The method consists of dividing the building footprint into small regions, for each of which a parameterized standard roof shape is chosen from a catalog in such a way that it best matches the point cloud of the corresponding roof area. A model-based approach usually means that small structures such as dormers are lost. However, these structures affect the gradient and position of the model roof segments. To obtain more accurate main roof facets that can be used as the basis for adding higher level of detail objects, a correction is required. The true plane equation of each roof facet of the given model is estimated from the point cloud using the Random Sampling Consensus (RANSAC) algorithm. If a model facet needs to be adjusted, its boundary polygon has to be recalculated. This is done with a mixed integer linear program, which changes the positions of the vertices so that they lie on as many roof planes as possible. Vertices on the cadastral footprint are allowed to be moved only on the footprint, other vertices have to stay within the (not necessarily convex) footprint polygon. In this paper, such a program is presented and applied to city models of North Rhine-Westphalia.

Optimizing Load-Bearing Truss Structures for Additive Manufacturing in Bending Processes

Julian Mrochen
Universität Siegen, Germany; julian.mrochen@uni-siegen.de

The global trend towards individualization, coupled with the rise of small batch sizes and increased product diversity within modular systems, is fostering a shift in manufacturing paradigms from mass production to flexible and scalable manufacturing. In this context, we present a case study focusing on the bending process, which exemplifies the need to design and optimize the underlying load-bearing structure to meet technical requirements effectively. Specifically, we address the challenge of designing a truss system capable of efficiently bearing the loads inherent in the bending process. A key aspect of our approach is the meticulous calculation of compliances, given their pivotal role in ensuring the structural integrity of the bending process. To achieve this, we leverage established Operations Research (OR) methodologies in conjunction with engineering principles. Our methodology aims to establish a robust framework for optimizing truss structures, with a unique emphasis on the utilization of additive manufacturing. This distinctive approach addresses the specialized nature of manufacturing trusses through additive processes, ensuring the efficacy of the optimization framework within this innovative manufacturing context.

Optimizing workspace utilization: A case study on flexible workspace industry in Oslo

Mehdi Sharifyazdi, Christopher Manalo, Kendra Swaine
BI Norwegian Business School, Norway; mehdi.sharifyazdi@bi.no

Facing increased operational costs and strong competition, a leading company in the flexible workspace industry struggles with a square meter efficiency of just 33% in Oslo, rendering just 19,800 out of 60,000 sqm saleable and resulting in lost clients and under-utilized spaces. This study addresses the challenge of enhancing square meter efficiency without extensive space reconfiguration, specifically through optimizing the use of auxiliary spaces such as business lounges and meeting rooms. By utilizing historical sales data and demand patterns across some of the company's locations in Oslo, the paper first forecasts demand and investigates stochastic variations to assess usage trends. It then identifies under-utilized auxiliary spaces that can be converted into revenue-generating workstations. Subsequently, an optimization model, structured as a multi-product newsvendor model, is developed to determine the optimal product mix. This model aims to minimize the total expected cost of shortage and under-utilization by adjusting inventory levels for each workspace type, subject to spatial configuration constraints. Anticipated challenges include managing the complications of multiple locations, varying spatial constraints in multi-floor buildings, and accommodating ongoing tenancies and fixed communal areas. The proposed approach offers insights for improving revenue potential and client retention by increasing the operational efficiency of workspace allocation.

TA 15: Logistics Platforms

Time: Thursday, 05/Sept/2024: 8:30am - 10:00am · *Location:* Wirtschaftswissenschaften 0534
Session Chair: Margaretha Gansterer

The Role of Digital Logistics Platforms for Regional Food Supply: A System Dynamics Approach

Christine Mendoza Pardo, Christian Fikar
University of Bayreuth, Germany; christine.mendoza-pardo@uni-bayreuth.de

In our work, we investigate the role of digital logistics platforms aiming to facilitate the share of regional food in the hospitality industry and communal catering. A systems thinking approach is applied to identify feedback structures and investigate underlying interdependencies. Therefore, findings from literature and two model regions were collected and modeled with the help of causal loop diagrams. The results indicate that digital solutions can help to overcome key obstacles in such systems, namely insufficient logistics solutions as well as a lack of communication and transparency. As initial drivers for more regional food in the hospitality industry and communal catering, we detected performance standards, community building activities and third-party funding, which in turn have a positive influence on investments in digitalization.

The impact of on-demand warehousing on the design of a multi-echelon distribution network

Teresa Melo[1], Isabel Correia[2]
[1]Saarland University of Applied Sciences, Germany; [2]Universidade NOVA de Lisboa, Portugal; teresa.melo@htwsaar.de

We address a multi-echelon distribution network design problem to determine the location and size of new warehouses, the closing of company-owned warehouses, the inventory levels of multiple products at the warehouses, and the assignment of suppliers as well as customers to warehouses over a multi-period planning horizon. New warehouses operate with modular capacities that can be expanded or reduced over several periods, the latter not necessarily having to be consecutive. Moreover, in every period, the demand of each customer for a particular product must be satisfied by a single warehouse. This problem arises in the context of on-demand warehousing, a business scheme that offers flexible conditions for temporary capacity leasing. The associated fixed warehouse lease cost reflects economies of scale both in the capacity size and the length of the lease contract. We develop a mixed-integer linear programming formulation and propose a matheuristic to solve this problem, which exploits the structure of the optimal solution of the linear relaxation to successively assign customers to open warehouses and fix other binary variables related to warehouse operation. Additional variable fixing rules are also developed, which are based on a scheme for managing inventories at warehouses and taking supplier capacities into account. Numerical experiments with randomly generated large-sized instances reveal that the proposed matheuristic outperforms a general-purpose solver in 74% of the instances by identifying higher quality solutions in a substantially shorter computing time.

Solving the Online On-Demand Warehousing Problem

Margaretha Gansterer[1], Sara Ceschia[2], Simona Mancini[3], Antonella Meneghetti[2]
[1]University of Klagenfurt, Austria; [2]University of Udine, Italy; [3]University of Palermo, Italy; margaretha.gansterer@aau.at

In On-Demand Warehousing, an online platform acts as a central mechanism to match unused storage space and related services offered by suppliers to customers. Storage requests can be for small capacities and very short commitment periods if compared to traditional warehousing models. The objective of the On-Demand Warehousing Problem (ODWP) is to maximize the number of successful transactions among the collected offers and requests, considering the satisfaction of both the supply and demand side to preserve future participation on the platform. The Online ODWP can be modeled as a stochastic reservation and assignment problem, where dynamically arriving requests of customers must be rapidly assigned to suppliers. Firstly, an online stochastic combinatorial optimization framework is adapted to the Online ODWP. The key idea of this approach is to generate samples of future requests by evaluating possible allocations for the current request against these samples. In addition, expectation, consensus, regret, and two greedy algorithms are implemented. All solution methods are compared on a dataset of realistic instances of different sizes and features, demonstrating their effectiveness with respect to the oracle solutions, which are based on the assumption of perfect information about future request arrivals. A newly proposed approach of risk approximation is shown to outperform alternative algorithms on large instances. Managerial insights regarding acceptance and rejection strategies for the platform are derived. It is shown how requests with large demand, long time frame, not very long spanning time, and average compatibility degree, are very likely to be rejected in the optimal solution.

TA 16: Manufacturing Planning for Modular Products

Time: Thursday, 05/Sept/2024: 8:30am - 10:00am · *Location:* Wirtschaftswissenschaften 0540
Session Chair: Linda Bentzen

Production Planning for Modular Products in Configure-to-order Environments

Franziska Elisabeth Strobel, Rainer Kolisch
Technical University of Munich; f.strobel@tum.de

In this research project, we consider the hierarchical production planning problem of a configure-to-order company that manufactures modular capital goods. Each customer order is represented and processed as one project. The production planning problem is formulated as a two-stage problem with one tactical problem and multiple operational problems. The solution of the tactical problem defines the constraints for the operational problems. The operational problems are formulated individually for specific production areas, such as workshop assemblies or mixed-model assembly lines. The tactical problem determines the start and finish times of aggregated activities, which define the feasible production planning periods for the operational problems. Further, the tactical problem decides in which production area, and thus, in which operational problem, the activities are processed. We formalize the tactical problem using a multi-mode resource-constrained project scheduling problem (MMRCPSP) with deterministic and constant resource requirements and deterministic duration across the activity's modes. The tactical problem uses a time horizon of several months and aggregated information to solve the objective of minimizing total weighted lateness concerning the due dates of customer orders. The operational problems deal with operational planning and thus focus on shorter planning horizons, more granular planning periods, and more detailed information. In each operational problem, activities are scheduled, and workers are assigned to workstations such that the time windows from the tactical problem are respected and the total overtime is minimized. We will present MIPs for both levels of the hierarchical approach. Furthermore, we will report on a computational study using real-world instances.

Integrated Master Scheduling and Sequencing for Engineer-to-Order Mixed-Model Assembly Planning

Robert Brachmann, Rainer Kolisch
TUM School of Management, Chair of Operations Management; Brachmann.R@uhlmann.de

This paper addresses integrated master scheduling and sequencing of mixed-model assembly in an engineer-to-order setting. Multiple orders containing models have to be assembled on multiple dedicated assembly lines. For each line, we must determine a model sequence, which must be maintained for all workstations. Depending on their skills, workers can be assigned to different workstations across lines. Workers can work undertime and overtime. For each type of workers, there is an aggregated working time account. The planning problem is to sequence the models and assign workers to the workstations. In a lexicographical approach, the primary goal is to start models as early as possible, while the secondary goal is to balance working time accounts. We model the problem as a mixed-integer optimization problem and undertake computational experiments on an instance set derived from a producer of packaging machines. Based on the computational study, we provide insight on the computation time and the value of working time accounts.

Integrated Production, Inspection, and Rework Planning for the Case of Different Defect Classes

Linda Bentzen
TUM, Germany; linda.bentzen@tum.de

We consider a dynamic lot-sizing model with rework and different failure classes where a known demand must be met in each period. When producing a lot size, a given percentage of the products does not meet the requested quality. A subsequent inspection process assigns the product to exactly one of several failure classes. The product can then be restored to as-new condition during a perfect reworking process where reworking times and costs depend on the failure class. For production and rework, there is a joint resource and production and rework of the same product cannot take place in the same period. The objective is to minimize the total costs. As the problem is NP-hard, we propose a Fix&Optimize (F&O) heuristic. In an iterative way, the F&O heuristic fixes a subset of the binary variables and optimizes the remaining variables. We consider two decomposition approaches, by period and by product. In a computational study we assess the performance of the heuristic and the MIP when solved with CPLEX for a set of generated test instances. We show that the F&O heuristic solves complex test instances within a reasonable time with very good solution quality. Furthermore, we provide managerial insight.

TA 17: Workforce Planning

Time: Thursday, 05/Sept/2024: 8:30am - 10:00am · *Location:* Wirtschaftswissenschaften 0544
Session Chair: Laura Maria Poreschack

A Unified Approach to Shift Design and Rotating Workforce Scheduling

Tristan Becker
TU Dresden, Germany; msci@tu-dresden.de

In many organizations, human resources are a primary cost driver. Consequently, careful scheduling of this resource is paramount. The shift design and scheduling process involves several steps, from recognizing staffing requirements to deploying a workable schedule. Based on the staffing requirements and shift design constraints, a set of workable shifts is devised. The shift scheduling process then determines the number of employees and assembles these shifts to a shift schedule. Traditionally, shift design and scheduling are treated as separate problems. This separation fails to address conflicts between design and scheduling objectives, potentially leading to inefficiencies when relying on predetermined shift designs. To address these challenges, we introduce a unified approach that integrates shift design with rotating workforce scheduling. In addition to the shift design objective function, we model an ergonomics objective function for the quality of the schedule. We solve the integrated problem using a branch-and-cut approach based on a compact formulation and graph representation, ensuring feasibility of shift designs by modeling the shift schedule as a Eulerian cycle of work sequences and rest periods. Experiments indicate that our approach can quickly solve problem instances based on the benchmark sets for shift design and rotating workforce scheduling. Results show that an integrated shift design and scheduling enables shift schedules with greatly improved ergonomics without deteriorating the shift design objective compared to the sequential planning approach.

Optimization of Workforce Planning: Satisfying Company Requirements and Employee Wishes

Emeline Tenaud
Hexaly, France; etenaud@hexaly.com

This talk describes an industrial application that helps schedule employees in a call center. The schedules are optimized for a week and aim to plan the activities of 30 to 200 employees, considering 2 to 5 different activities. Each employee has a weekly hourly contract and a skill level for each activity. The demand for the number of employees needed to perform each activity for a given week is determined by 30-minute periods. The goal is to meet this demand, and two penalty objectives are used to achieve this: minimizing understaffing and minimizing overstaffing.

A rule formalism has been defined to cater to each company's specific needs. These rules allow different situations to be modeled, such as "Every employee must perform this activity for a maximum of 3 hours during the day." They are included in the optimization model by adding an objective minimizing the penalty of non-respect for each rule. Furthermore, the employees' preferences and wishes are considered when creating schedules to improve the quality of work life and retain employees.

This highly combinatorial optimization problem involving complex business constraints has been efficiently modeled using Hexaly. The solver optimized this problem with optimality guarantees for medium-sized instances within 30 seconds of running time. Based on this optimization problem, an industrial web application for workforce planning has been developed and will be demonstrated during the talk.

Incorporating Preferences into Crew Scheduling Optimization – A Field Experiment

Laura Maria Poreschack, **Ulrich Thonemann**
University of Cologne, Germany; laura.poreschack@uni-koeln.de

Railway crew scheduling deals with generating train driver duties to cover a number of trips while minimizing costs. Duty feasibility is subject to various physical restrictions and regulations such as the maximum working time and operational requirements.

In times of strikes and driver shortages, accounting for employees' preferences gains importance. Including not only financial but also employee-centric goals could improve the satisfaction of the drivers and the attractiveness of the profession.

We consider the crew scheduling optimization tool used by a European railway freight carrier (ERFC). Duties are generated without consideration of any preferences. As preferences are often intangible or a non-linear combination of interacting characteristics, we employ machine learning to detect patterns. We train a classifier on 16,000 duties that were labelled as preferred or not preferred, and incorporate the duty classifier into the crew scheduling tool used by the ERFC.

We take this approach to the field, and test it with planning teams from all planning regions of the ERFC. Planners generate current schedules for their regions, and rate how these schedules meet their preferences. They also indicate duty characteristics that are most decisive for their preferences. We compare these with the influential features of the machine learning classifier, and see that our tool effectively captures preferences of the planners. Moreover, it is able to depict regional differences between planning teams accurately, and can generate schedules with more preferred duties accordingly. We also observe that incorporating preferences leads to schedules with comparable costs.

TA 18: Green Transition Scenarios

Time: Thursday, 05/Sept/2024: 8:30am - 10:00am · *Location:* Theresianum 0601
Session Chair: Thomas Kirschstein

Eco-dorm: How to save energy as a residential student community.

Constanze Liepold[1], Paul Fabianek[1], Reinhard Madlener[1,2]

[1]Institute for Future Energy Consumer Needs and Behavior (FCN), School of Business and Economics / E.ON Energy Research Center, RWTH Aachen University, Germany; [2]Department of Industrial Economics and Technology Management, Norwegian University of Science and Technology (NTNU), Norway; constanze.liepold@eonerc.rwth-aachen.de

In view of global climate change, it is important to save energy and therefore emissions in all sectors. The German building sector is particularly lagging behind the savings targets. While single-family homes are increasingly being renovated and PV systems installed, it is particularly difficult to implement such measures in multi-party buildings, especially if they are occupied by low-income earners. In this context, we examine how student dorms can be transformed in terms of energy efficiency taking energy saving measures. The focus of the investigation was on the preferences and objective systems of student occupants. In order to ensure a reflective and systematical investigation, Value-Focused Thinking was applied in a workshop with 50 occupants of a student dorm in Aachen, Germany. The final aggregated fundamental objectives, which were developed by the workshop participants in group work as elementary for the joint implementation of energy-saving measures, are: feasibility, profitability, health, ecological sustainability, comfort, social harmony. Using the Analytic Hierarchy Process approach for a Multi-Criteria Decision Analysis, these fundamental objectives were weighted by the participants. Fulfilling these fundamental objectives would ensure that the initiatives are not only practical and economically viable, but also enhance the well-being and environmental responsibility of the occupants. By prioritizing these objectives, student dorms can foster a culture of sustainability that resonates with students' values and daily lifes, ultimately leading to more successful and widely adopted energy saving practices.

The future spatial distribution of onshore wind energy capacity based on a probabilistic investment calculus

Yannik Pflugfelder, Christoph Weber

University of Duisburg-Essen, Germany; Yannik.Pflugfelder@uni-due.de

The spatial distribution of future renewable capacities is a key determinant for the develop-ment of appropriate grid expansion plans. This is particularly relevant for onshore wind energy. Thereby, existing studies mostly extrapolate the future installations based on existing capacities and available sites. As wind farm projects are developed by private (or state-owned) companies, the economic rational of investing at specific sites deserves more attention. Therefore, the present contribution develops a model of economic choice for wind investments based on site-specific computations of the achievable net present value taking into consideration the land availability at the regional level. Thereby the site-specific investment decisions are modeled as (partly aggregated) discrete choices. The net present value is computed from investment costs and expected yields, which can be estimated based on wind speed time series and power curves. Available land can be identified by excluding settlement, infrastructure, and nature conservation areas with appropriate buffers as well as sites with topographically unsuitable profiles. The model is formulated as a nested logit model which captures the interdependencies between choices on two levels: the probability of investment in a particular region on the first level and the probability of installing a specific turbine type there on the second level. In an application for Germany with the target capacities of the German Renewable Energy Act, the model delivers a spatial distribution of the capacities on NUTS 3 level. The model also enables the derivation of the necessary compensation level and the most frequently installed turbine types.

Evaluating Effects of Policy Measures on Renewable Fuel Supply Chain Development

Mohammad Zardoshti, Grit Walther

RWTH Aachen, Germany; mohamad.zardoshti@om.rwth-aachen.de

Policy measures significantly influence the development of renewable fuel supply chains (RFSC) by determining the demand, technology selection, and infrastructure evolution necessary for providing renewable fuels for the transport sector. Such policies, including mandates for renewable fuel shares, targets for reducing GHG intensity of fuels, and carbon pricing measures on supplied fuels, are pivotal for encouraging the transport sector towards climate neutrality. However, comprehensive assessments are needed to understand the impact of these measures on the overall GHG targets and costs of RFSC, including the potential contribution of the different transport subsectors and the effect on fuel supply chains, as well as their interrelations.

Our research aims to analyze policy measures that promote climate neutrality within the transport sector by examining their influence on the design of RFSCs. We employ a multi-period mixed-integer linear programming model that enables the evaluation of policy frameworks based on total net present costs and GHG emission savings. Through identifying Pareto-efficient solutions, we investigate the trade-offs between the two objective functions. Additionally, factorial analysis reveals the impacts of contributions of policy measures on the design of RFSCs. The results from the Pareto frontier show that higher cumulative GHG emission savings result in higher net present costs. Furthermore, the study indicates that an earlier supply of renewable fuels in the transport sector leads to higher GHG emission savings. In conclusion, this analysis offers insights into how policy measures can influence the renewable fuel supply trajectory and contribute to achieving climate neutrality goals in the transport sector.

Modelling and evaluating the economic impact of sustainable future scenarios for a greenhouse gas-neutral chemical industry

Thomas Kirschstein, Lisa Schubert

Fraunhofer IMW, Germany; thomas.kirschstein@imw.fraunhofer.de

In our work we identify and evaluate transformation pathways for a sustainable chemical industry in Germany in 2045. Such transformation scenarios include 1. a greenhouse gas-neutral energy supply and 2. the diversification of carbon-based raw materials, e.g., CO2 from direct air capture, biomass, and plastic waste. Different technologies as well as availability and prices of resources and feedstocks are considered in an investment optimization model. The model allows us to evaluate technology paths with respect to operational and investment cost, environmental effects, and societal impacts (e. g. measured by number of jobs and value added). Technological paths are mapped for the production of conventional chemical base materials, primarily

aromatics and olefins, and includes their synthesis via chemical recycling, Fischer-Tropsch processes, and methanol derivatives. Biomass streams and plastic waste play a primary role as sustainable carbon sources that are used for synthesis gas and pyrolysis oil production, respectively. We explicitly model synergies in existing and future Verbund site configurations.

In the evaluations, we analyse technological paths will evolve under different regulatory scenarios. We consider e. g. waste and biomass potentials as well as operational and investment costs along with regulatory and market factors like electricity cost, GHG cost and CCS budgets.

Scenario evaluation includes an assessment of impacts for chemical industry and economy by estimating e. g. value added, jobs created as well as investments and operation cost of the optimized value chains. Additionally, we analyse resulting infrastructure requirements, especially for scenarios with high value added.

TA 19: Decomposition Methods for Large-scale Energy Planning

Time: Thursday, 05/Sept/2024: 8:30am - 10:00am · *Location:* Theresianum 1601
Session Chair: Leonard Göke

Optimal long-duration storage in decarbonized energy systems under uncertainty: A refined stochastic dual dynamic programming approach

Felix Sebastian Schmidt

DIW Berlin, Germany; fschmidt@diw.de

As energy systems around the world become increasingly dependent on variable renewable energy sources, optimal spatial and temporal balancing over different distances and time scales by means of networks and storage has become a central question of interest. Long-duration storage (LDS), based on green hydrogen or its derivatives, is envisioned to take a pivotal role in solving it. Formulated as deterministic linear programs, most energy system planning models determine optimal LDS capacities based on one or few weather years, assuming perfect foresight in the dispatch stage leading to potentially highly sub-optimal capacity choices. Recasting the planning problem as a multi-stage stochastic program with a planning stage followed by several operational stages, we employ a stochastic dual dynamic programming (SDDP) algorithm to capture inherent weather uncertainty and to abandon the perfect foresight assumption.

Relevant model sizes require computational refinements to the original SDDP algorithm to remain tractable. We adopt and compare several extensions suggested in recent literature contributions and test their efficacy for the energy system planning problem at hand. These extensions include stabilisation and warm starts, quasi-Monte-Carlo sampling schemes, inexact oracles and Chebyshev cut generation.

Analyzing decomposition approaches for large-scale energy system models

Lene Marie Grübler[1,2], Felix Müsgens[1]

[1]Brandenburg University of Technology Cottbus Senftenberg; [2]50Hertz Transmission GmbH, Germany; grueblen@b-tu.de

The share of renewable energy generation capacities will rise substantially in the upcoming decades. Their integration requires expansion of power grids and flexibility options, such as storage solutions. Current research in the field of energy system modelling therefore often aims at optimizing these technologies jointly, resulting in complex optimization problems to be solved. Their structure reveals decomposability on the temporal as well as on the spatial scale, which allows the application of decomposition techniques to keep them computationally tractable. Investment decisions and storage levels represent linking variables on the temporal scale and power exchanges between regions can be defined as linking variables on the spatial scale. Suitable decomposition techniques for dealing with linking variables are Benders decomposition and Consensus ADMM. Within this work we analyze which of these techniques is most favorable for solving large-scale multi-regional energy system models. Furthermore, we analyze which decomposition of the original problem, temporal, spatial or combined, can be solved most efficiently by which algorithm. We deliver a case study for the comparison of different decomposition strategies for a specific problem type and contribute to the open question of which decompositions are most suitable for which type of optimization problems.

Decomposition of stochastic energy system optimization models – time-splitting in Benders Decomposition vs. PIPS-IPM++

Shima Sasanpour[1], Manuel Wetzel[1], Karl-Kiên Cao[1], Andrés Ramos[2]

[1]Deutsches Zentrum für Luft- und Raumfahrt e. V. (DLR), Germany; [2]Universidad Pontificia Comillas, Spain; Shima.Sasanpour@dlr.de

Energy system optimization models (ESOMs) are useful tools to analyze the decarbonization of our current energy system. However, the underlying input data is subject to uncertainties. Although these uncertainties can substantially impact the structure of the energy system, they are often not taken into account. By applying stochastic programming (SP) the uncertainties can be considered within a single optimization run to achieve risk hedging.

Even without considering uncertainties, ESOMs can become exceedingly large when a high spatial and technological granularity is needed, e.g. for sector coupling. Therefore, acceleration techniques are required to keep the models solvable, especially when taking SP into account. Benders Decomposition (BD) is a method that is typically applied to SP models. Since the stochastic scenarios can be independently optimized within the subproblems, they can be easily parallelized along the stochastic scenario dimension. However, the number of scenarios is rather small in comparison to the number of time steps that are considered in hourly resolved ESOMs.

To further exploit the parallelization potential of stochastic ESOMs, we apply an additional decomposition along the time dimension to two different methods. First, we apply time-splitting to BD in combination with MPI. Second, the performance is compared to the parallel high-performance computing solver PIPS-IPM++. The solver, mainly applied on temporally decomposed ESOMs, has recently been extended to also incorporate stochastic optimization, which enables an additional decomposition along the stochastic scenario dimension.

Benders decomposition for energy planning under climate uncertainty

Leonard Göke, Stefano Moret, André Bardow

ETH Zürich, Energy and Process Systems Engineering, Switzerland; lgoeke@ethz.ch

Climate change mitigation requires supplying the power, heating, and transport sectors with renewable energy sources such as wind, solar, and hydro. Renewable supply and energy demand vary substantially across seasons or years, change with the climate, and cannot be predicted in the long-term. As a result, periods with high residual demand ranging from Dunkelflauten to multi-year energy draughts threaten energy security.

This work investigates how to secure renewable energy systems against climate uncertainty. We introduce a stochastic programming formulation that remains computationally tractable but can consider an extensive sample of weather conditions and limit foresight. In addition, we deploy a stabilized Benders algorithm to leverage distributed computing when solving the resulting stochastic optimization problem.

Building on this method, we analyse energy security in an interconnected European energy system characterized by fluctuating renewable supply and electrification. The analysis considers seasonal and intra-annual storage from hydro reservoirs or synthetic fuels, importing electricity or synthetic fuels, and renewable overcapacity or load shedding as security options.

Samples for uncertain and weather-sensitive energy system inputs build on ERA5 reanalysis data from 1982 to 2016. Thanks to the introduced formulation, capacity planning must not consider the entire dataset but relies on a subset to reduce problem size. A subsequent Monte-Carlo analysis with an operational rolling horizon model estimates the expected unserved energy for the computed capacity setups using the entire dataset.

Preliminary results show that energy security is critical to include in future energy planning but, at the same time, manageable when addressed correctly.

TA 21: Railway Applications 1

Time: Thursday, 05/Sept/2024: 8:30am - 10:00am · *Location:* Nordgebäude ZG 1070
Session Chair: Arturo Crespo Materna

A modular simulation-based framework for the assessment of optimised rail traffic rescheduling strategies

Konstantinos Rigos[1], Egidio Quaglietta[1], Federico Naldini[2], Paola Pellegrini[2], Rob M.P. Goverde[1]

[1]Department of Transport & Planning, Delft University of Technology, The Netherlands; [2]COSYS-ESTAS, Université Gustave Eiffel , France; k.rigos@tudelft.nl

Several rail traffic management approaches have been suggested in literature, mostly proposing either centralised or decentralised optimisation models. However, the impact of these models on both traffic flow and passenger experience needs further investigation before receiving acceptance from the railway industry. To this end, a modular simulation-based framework is proposed in this research which allows assessing impacts of rail traffic rescheduling approaches on both train service performances and passenger satisfaction. The developed framework interfaces modules for the simulation of rail traffic and passenger flows, with a rail traffic rescheduling algorithm, to assess optimised traffic plans provided by this latter on train punctuality and passenger travel times for different delayed traffic scenarios. A scalable messaging interface, Zero-MQ, is adopted for an efficient and tool-agnostic data exchange among the framework modules.

In the presented setup the state-of-the-art RECIFE-MILP rail traffic rescheduling algorithm is assessed by using the EGTRAIN rail traffic micro-simulation platform and a specifically-developed microscopic passenger flow model to describe passenger-dependent train dwell times at stations. In this setup, the impact of an open-loop configuration of the RECIFE-MILP rescheduling is compared to a rolling-horizon setup where traffic plans are regularly adjusted based on current traffic conditions. Those configurations are benchmarked against the original train schedule regarding train arrival delay and total passenger travel times. Results show the ability of the framework to evaluate different setups and algorithms for optimised rail traffic management and will be further used to assess novel paradigms including self-organising train operations.

A Multi-Commodity Flow-based Approach to Integrated Train Timetabling, Locomotive and Wagon Set Scheduling in Rail Freight Traffic, with a Case Study of DB Cargo Polska

Jonasz Staszek, Alexander Martin

Technische Universität Nürnberg, Germany; jonasz.staszek@utn.de

Rail freight operators have long benefited from planning support based on mathematical optimization. Due to the highly complex nature of resource allocation problems in this industry, they have typically been tackled on an isolated basis. Achieving new levels of efficiency requires a broader perspective that considers more than one group of resources at a time. In this work, we study an integrated train timetabling, locomotive and wagon set scheduling problem for a rail freight carrier, in a long-term planning perspective. The objective is to find the optimal allocation of locomotives and wagons, measured in terms of costs or alternatively the number of locomotives or wagons used. In the problem we consider, some of the trains have a fixed timetable, while others have to be scheduled by our algorithm. On the one hand, this opens up additional optimization potential, but on the other, it adds computational complexity. In addition, mileage-based locomotive maintenance constraints must be considered. We model this problem on the basis of two interconnected multi-commodity flow problems with additional constraints. To validate the effectiveness of our approach, we conduct experiments using real-world data provided by DB Cargo Polska S.A.

Capacity Optimal Planning of Railway Lines under ETCS Level 2 Without Signals (ETCS-L2oS)

Arturo Crespo Materna, Nenad Grubor, Andreas Oetting

TU Darmstadt, Institute for Railway Engineering Germany; crespo@verkehr.tu-darmstadt.de

The continuous effort to increase railway capacity is supported by the introduction of modern technologies such as the European Train Control System (ETCS). By the end of 2028, more than 4,000 kilometers of German railway lines are expected to be equipped with ETCS L2. To ensure the capacity gains brought by these systems, optimizing block sizes (distance between ETCS markers) is of central importance. Within this context, the challenge lies in ensuring demand-oriented block sizes that can meet current and future capacity needs. Another challenge arises from the currently established planning rules applicable to ETCS-L2oS (without signals) regarding the placement of ETCS elements (ETCS signals and balizes) on the infrastructure. Planning restrictions can currently limit the placement of ETCS elements; however, these restrictions are not absolute and can change over time.

There are a limited number of approaches for optimizing block sizes in ETCS L2oS. These approaches aim to adjust block sizes to specific train sequence scenarios and do not consider restrictions on the placement of ETCS signals. Thus, prevailing practical requirements are not fully met. Furthermore, existing approaches do not clearly explain how to respond to the increasing trend in future capacity needs. This contribution seeks to address the open questions by tackling two challenges. The first challenge involves specific steps to optimize block sizes on ETCS L2oS lines while considering flexible planning restrictions. The second aspect offers a strategic solution for a resilient planning, which can be flexibly extended to allow greater capacity than is currently required.

TA 22: Urban Transportation and Traffic

Time: Thursday, 05/Sept/2024: 8:30am - 10:00am · *Location:* Nordgebäude ZG 1080
Session Chair: Julia Sudhoff Santos

A Congestion-Aware Rerouting Heuristic for Scheduled Road Traffic Based on Traffic Simulation

Paul Rieger, Crespo Arturo, Oetting Andreas
Institute for Railway Engineering, Technical University of Darmstadt, Germany; rieger@verkehr.tu-darmstadt.de

The increasing volume of personal motorized vehicles (PMVs) in cities has become a serious issue, leading to congestion, noise, and air pollution. To mitigate these negative externalities, new forms of mobility such as ridepooling promise to redefine urban road traffic by offering mobility as a service. Assuming that this may become a predominant mode of individual transport, urban traffic could potentially become more manageable through centralized routing decisions.

The presented heuristic is built upon this assumption and detects bottlenecks based on traffic simulation. For each bottleneck, the heuristic systematically proposes efficient rerouting options to alleviate traffic congestion, taking into account the severity of congestion and the requirements and priorities of each vehicle. The traffic simulation employed is based on a realistic default traffic scenario for a segment of the city map of Darmstadt, which serves as the initial solution.

The evaluation of the results is based on the resulting utilization of infrastructure and the "travel time quotient" ("Beförderungszeitquotient"), comparing the actual travel times with the minimum travel times that would occur without any congestion. Trade-offs between both parameters are analyzed, and the results are systematically compared to the default solution.

Optimizing Traffic Light Control to Minimize Vehicle Delay Time in a port area: A Simulation Optimization approach

Bruna Helena Pedroso Fabrin[1], Wolfgang Brüggemann[1], Larissa Timm[2], Alwin Brehde[2], Carsten Eckert[3], Ralf Sahling[3], Justin Wilckens[3], Julia Hertel[1], Ulrich Baldauf[2], Leif-Erik Gorris[2]
[1]Universität Hamburg, Germany; [2]Hamburg Port Authority, Germany; [3]Hamburg Port Consulting, Germany; bruna.fabrin@uni-hamburg.de

During a day, traffic demand greatly varies; for example, it is expected more traffic in early morning and late afternoon due to people commuting to and from work. As congestion builds up, commuters become more irritated and more susceptible to mistakes. Therefore, searching for improved solutions is fundamental, as one or two extra seconds of green light phase can greatly alternate the traffic situation.

An important indicator for evaluation of traffic is called Vehicle’s Delay Time (VDT), which is defined as the extra time that vehicles need to complete its journey due to congestion or red traffic lights in comparison to a clear way journey. As part of the HafenPlanZen project, a project to create a strategic port planning, our objective is to use a simulation model of a port area of the city of Hamburg in Germany to optimize the phase configuration of traffic light signals in an intersection and to minimize VDT. A simulated annealing optimization algorithm was chosen, because it has an easy implementation and it has been shown to be successful with many problems.

The simulation model is already completed and the focus now is on implementing the optimization algorithm. In order to converge to a solution faster, we plan on using the Downhill Simplex Method developed by Nelder and Mead in 1965. We will present the traffic scenario implemented today and the optimized solution to show the improvement.

Developing Heuristic Software for Track Occupation in Vehicle Parking Areas

Patrick Buhle, Benedikt Kordus, Christin Schumacher, Uwe Clausen
TU Dortmund, Germany; patrick.buhle@tu-dortmund.de

Efficient light rail turnaround planning and assignment to overnight parking spaces are essential for optimizing urban public transport systems. This study presents a software-based light rail scheduling tool developed for DSW21, a communal transport company in Dortmund, Germany, to automate a previously manual process.

The challenge of this task lies in meeting the timetable and simultaneously scheduling light rails to accessible parking spaces. Furthermore, the parking areas have unique constraints that restrict the scheduling decision, such as the number of parking spaces available or the consideration that a light rail can only leave if another does not block the departure.

Our tool takes timetable data as input and generates schedules using a First Come, First Served heuristic with constructively assigning light rails to accessible parking spaces. The tool reduces the need for manual schedule readjustments, consistently achieving placement rates of 95% to 100% for routine timetables. Moreover, we achieved user-friendly functionality and respected company standards and design conventions by involving users in the development process. The tool incorporates editable user files to facilitate practical utility and ensure adaptability for future rail modifications. Additionally, our tool tracks light rail maintenance cycles to determine whether the maintenance requirements are met and identifies light rails that must be driven to the depot outside the timetable.

Moving forward, we aim to improve the algorithm to increase placement rates for high-volume timetables and optimize scheduling within maintenance constraints to reduce the number of manual schedule adjustments ex-post, thus continuously improving the company’s light rail operations.

Computing safe paths to school – modeling pedestrian safety along streets and crossing points

Kathrin Klamroth, Michael Stiglmayr, Julia Sudhoff Santos
University of Wuppertal, Germany; sudhoff@uni-wuppertal.de

The safety of a street for school children can be modeled by using ordinal costs, i.e., ordered categories like safe, medium and unsafe. Ordinal costs model the quality of objects whenever numerical values are not appropriate, i.e., it is impossible to quantify how much better a safe street is compared to a medium safe street.

In this talk, we present a solution method for solving ordinal shortest path problems by a transformation into associated multiobjective shortest path problems. This allows us to compute a set of efficient solutions with different trade-offs between path length and safety. The choice of a route depends then on the individual preference of the decision maker. However, the safety of a school path is highly depending on the crossing points and not only on the longitudinal traffic. We discuss the difficulties of integrating safety of crossing points and streets in one optimization model and present different modeling ideas.

TA 23: Dial a Ride Problems

Time: Thursday, 05/Sept/2024: 8:30am - 10:00am · *Location:* Nordgebäude ZG 1090
Session Chair: Kendra Reiter

The stochastic electric dial-a-ride problem with recourse

Léa Ricard[1], Michel Bierlaire[2]

[1]EPFL, Switzerland; [2]EPFL, Switzerland; lea.ricard@epfl.ch

The dial-a-ride problem involves planning routes for a fleet of vehicles to pool passengers, based on ride requests that specify an origin, destination, and an arrival time window. The electric dial-a-ride problem also incorporates scheduling charging activities to ensure vehicles remain operational. Traditional deterministic approaches often plan conservatively for worst-case scenarios or lack robustness by only accounting for expected energy consumption. To address these limitations, we introduce a two-stage stochastic model with recourse for the electric dial-a-ride problem in this work. Our model leverages real-time data on the state of charge, permitting adjustments to the planned charging time if deviations in energy consumption occur. We also develop an extension of the event-based graph, the so-called event-energy graph, which encodes energy consumption information. This graph features separate layers for each energy level, where events are connected by energy-feasible arcs. Furthermore, we propose an adaptive large neighborhood search algorithm to solve benchmark instances of the electric dial-a-ride problem. We assess the effectiveness of our approach across different ride-pooling systems employing various battery electric vehicles.

A supervised machine learning framework to predict the request fit for dynamic dial-a-ride problems

Simon Mader, Pirmin Fontaine, Stefan Voigt

Catholic University Eichstätt-Ingolstadt, Germany; simon.mader@ku.de

Efficient public transport is key to the sustainable mobility transformation, especially in rural areas where traditional line-based bus services struggle due to the sparse demand. Therefore, innovative on-demand buses, with flexible routes and schedules, present a practical solution for improving rural mobility. Public transport providers aim to maximize the number of served passengers with these on-demand buses but operate within limited resources, leading to challenging decisions on accepting or rejecting passenger requests. Moreover, the dynamic booking process requires an immediate decision without knowing the impact of the request on potential future requests. Therefore, the problem of predicting the request fit for dynamic passenger-maximizing dial-a-ride problems (PM-DARPs) emerges.

To address this problem, we introduce the request fit predictor (RFP) framework. Within this framework, we model the request fit as a binary classification task and learn the fit with supervised machine learning models, having perfect information about historical requests. The RFP combines the request fit learned from static PM-DARPs with dynamic components of the cheapest insertion to guarantee feasibility, integrate request prescience, and facilitate an immediate acceptance/rejection decision.

The RFP is tested on real-life data from a German public transport provider and serves 26.19% more passengers than the current business practice. Compared to the cheapest insertion, the RFP not only serves 7.48% more passengers but also covers 6.68% less distance. In the presentation, we will discuss the trade-offs of the RFP's performance KPIs and give further insights into the framework's fairness and adaptability.

Modelling Approaches for the Line-Based Dial-a-Ride Problem

Kendra Reiter[1], Marie Schmidt[1], Michael Stiglmayr[2]

[1]University of Würzburg; [2]University of Wuppertal; kendra.reiter@uni-wuerzburg.de

What if we use existing infrastructure to establish new mobility concepts? The well-established schedule-based bus system relies on fixed routes and fixed bus stops in its operation, offering high predictability even when there are high variations in demand. This concept is rivaled by on-demand systems, which offer very high flexibility with little predictability. We bridge the gap between the two systems with the line-based dial-a-ride problem (liDARP), where vehicles travel along a pre-defined sequence of bus stations, with the flexibility of taking shortcuts, waiting at stations, or turning if no passenger is on board. Service promises ensure operational quality to encourage users to utilize our system.

We propose three Mixed-Integer formulations to model the liDARP. The first employs flexible sublines, where sequences of sublines driving in opposite directions transport passengers between bus stations. The second is based on the classical 3-index DARP formulation, where a specifically constructed graph network ensures all directional constraints are met. The last model is an event-based formulation, where nodes represent events and arcs the transition between them, adapted to meet our specific problem constraints. We examine our formulations in diverse operational contexts, additionally comparing the efficiency of a classic DARP formulation and a schedule-based bus.

TB 01: Plenary Klemperer

Time: Thursday, 05/Sept/2024: 10:30am - 11:30am · *Location:* Audimax
Session Chair: Martin Bichler

Multiproduct Auction Design

Paul Klemperer

University of Oxford, Great Britain, -; paul.klemperer@nuffield.ox.ac.uk

I will talk about my work on multiproduct auctions, including for government debt (a “product-mix auction” for substitute goods for the Bank of England), and for ecosystem conservation (an auction to procure a mixture of substitutes and complements habitat to help preserve the European turtle dove); some of this is joint work with Elizabeth Baldwin, Martin Bichler, Max Fichtl, Paul Goldberg, Edwin Lock, and Alex Teytelboym.

TC 01: GOR Master Thesis Award

Time: Thursday, 05/Sept/2024: 11:30am - 1:00pm · *Location:* Audimax
Session Chair: Kevin Tierney

Optimization of Transformation Pathways for the Residential Building Sector

Roman Delorme

Chair of Operations Research, RWTH Aachen University, Germany; delorme@or.rwth-aachen.de

Transformation pathways provide information about which action to take in which building and which year to transform residential building stocks. We define the problem of determining optimal transformation pathways of residential building stocks and introduce a MILP model for this problem. To accelerate the solving process, we propose different Benders decompositions of the original model. For further acceleration, we introduce constraint modifications to generate Benders cuts faster as well as valid inequalities for our Benders relaxed master problems (RMPs) and a tailored Benders optimality cut strengthening technique. We further implement a primal construction heuristic for the Benders RMP and an in-out method to improve the dual bound at the root node. The Benders cut separation process is embedded into the branch-and-cut algorithm of the MILP solver Gurobi. Based on the German Census 2011, we introduce instance sets to test the algorithmic implementations on which we heuristically refine solution strategies based on aforementioned features. For instances with 50 buildings and a 20 years time horizon, the best-performing strategy yields relative MILP gaps of 5% while Gurobi attains relative MILP gaps of 20% and 10% if performing a warm start with our construction heuristic.

Stochastic Dynamic Multi-Period Technician Routing with Rework

Jonas Stein

Otto-von-Guericke Universität Magdeburg, Germany; jonas.stein@ovgu.de

Home services play an important role for business operations across various fields, such as after-sale services or craft businesses. In each case, technicians are sent to customer homes to complete on-site repair tasks. In this paper, we assume that workforces are heterogeneously qualified and that tasks require different skill levels. In contrast to other works in this field, we explicitly account for possible service failures due to a lack of technician skill. Tasks of higher complexity may remain unresolved, requiring revisits and rework. This consequently incurs additional resource investment and service delays. As we show in this paper, combining multiple dimensions (e.g., service deadlines, skill levels) during decision-making mitigates future service delays and resource investments. To this end, we introduce a cost-function approximation architecture to anticipate long-term implications at early decision points. In line with our objective to minimize overall customer delay, our method adapts its focus across multiple streams. This involves prioritizing the service of customers with imminent deadlines to avoid short-term delay, improving routing efficiency for increased customer visits, and assigning tasks to prevent service failures and rework. For various indicators (e.g., service delay, resource investments, rework), the results of a numerical study demonstrate that our anticipatory solution policy outperforms alternative benchmark policies that emphasize isolated goal dimensions. Our proposed policy achieves a fairer regional service distribution compared to benchmark methods while sustaining customer retention and ultimately enhancing operational performance.

On the Complexity of Crane Scheduling

Maximilian von Aspern

Technische Universität München, Germany; maximilian.aspern@tum.de

Motivated by a real-world application in industrial storage yards, we consider the problem of scheduling predetermined container relocation moves by an automated twin-crane system. We show that this problem, which we call Twin-Crane Scheduling, is NP-hard (already in a simpler setting where some constraints are relaxed or dropped entirely). Further, we prove that even a polynomial-time approximation scheme cannot exist for this problem unless P = NP. However, we show that the optimal solution can easily be approximated within a factor of 2 through a simple list scheduling algorithm. Finally, we establish a connection between a generalized crane scheduling problem and scheduling unit-time jobs on three or more machines under precedence constraints, the complexity of which has been a long-standing open problem.

TC 02: Optimization for Learning

Time: Thursday, 05/Sept/2024: 11:30am - 1:00pm · *Location:* Theresianum 0602
Session Chair: John Alasdair Warwicker

Towards Creating Robust Adversarial Examples for DNNs by MILPs

Jörg Rambau, Ronan Richter

Chair of Economathematics, University of Bayreuth, Germany; Ronan.Richter@uni-bayreuth.de

Deep Neutral Networks (DNNs) have been gaining more and more attention during the last few years. As a growing number of companies and customers begin to use DNN-based systems, governments have taken first actions into regulating AI-applications' use. Thus, there also is an increasing interest for methods to analyze the trustworthiness of a DNN and its results along with the limits of its applications.

A long-established demonstration of the shortcomings of DNNs is an Adversarial Examples. Adversarial Examples are marginally alternated versions of regular input data, that lead a DNN into wrong answers. Fischetti and Jo (2018) have shown, that such Adversarial Examples can be systematically generated by using mathematical programming. The application of their method allows to find Adversarial Examples, that are provably optimal in respect to a given criterion, e.g. the distance to some given input. However, such examples are tailored to one specific DNN and its parameters and may therefore not work for slightly different DNNs. Working in the direction of addressing this point, we are giving a mixed-integer programming model for generating Adversarial Examples, that incorporate robustness to small changes in the weights and biases of a DNN. For reasons of solvability, we will initially illustrate the impact of robustification using relaxations of the model. Additionally, we will present experimental results on the influence of various factors, e.g. selection of training data or structure of the DNN, on the transferability of our Adversarial Examples.

Integrating Machine Learning with GAMSPy

Hamdi Burak Usul

GAMS Software Gmbh, Germany; busul@gams.com

GAMSPy seamlessly combines Python's flexibility with the modeling prowess of GAMS. This combination offers promising avenues particularly in merging the realms of machine learning (ML) and mathematical modeling. While GAMS is proficient in indexed algebra, ML predominantly relies on matrix operations. To facilitate ML applications, our research focuses on incorporating commonly used ML operations into GAMSPy. In our presentation, we illustrate the practical implications by demonstrating the generation of adversarial images for an optical character recognition network using GAMSPy. We demonstrate the adaptability of GAMSPy and its potential utility in ML research and development endeavors. Furthermore, we explore future directions, including planned OMLT integration, highlight distinctions between GAMSPy's approach and existing alternatives.

A Mixed-Integer Linear Programming Framework for the Adversarial Training of Neural Networks

John Alasdair Warwicker, Steffen Rebennack

Karlsruhe Institute of Technology, Germany; john.warwicker@kit.edu

The training of neural networks (NNs) is a necessary task to improve their generalisation ability, measured by their performance on unseen inputs. However, even trained NNs can be vulnerable to adversarial inputs, which are minimally perturbed versions of standard inputs that are incorrectly labelled by the NN. The adversarial training of NNs can help to increase their robustness and guard against adversarial attacks. Recently, mixed-integer linear programming (MILP) models have been presented which are used to model the process of classification through trained NNs. One prominent application of such models is the ability to generate adversarial examples through providing constraints on the target input while minimising the level of perturbation. MILP models have also been presented for training NNs, showcasing comparable accuracy to traditional stochastic gradient descent approaches.

In this work, we use recent advances in the field of MILP to present the adversarial learning of NNs as an optimisation problem. We present a number of settings for the presented framework which allow for training against various settings of adversarially generated inputs, with the goal of increased robustness at minimal cost to performance. Experimental results on the MNIST data set of handwritten digits evaluate the performance of the proposed approach, and we discuss how the framework fits within the state-of-the-art.

TC 03: Explainability and Interpretability 2

Time: Thursday, 05/Sept/2024: 11:30am - 1:00pm · *Location:* Theresianum 0606
Session Chair: Jörn Maurischat

Bridging the Gap: Explainable Optimization by Communicating Vessels

Miguel Krause[1], Sebastian Hien[2], Lena Klosik[2], Michael Kreimeier[2]
[1]E.ON Digital Technology GmbH, Germany; [2]E.ON Deutschland GmbH; miguel.krause@eon.com

We present a new approach to explain the input-output relationship of black-box optimisations based on the fundamental principle of communicating vessels in physics. We find, that a distributed output set can be directly linked to the corresponding input sources within a hierarchical framework. This approach can be applied to any type of optimisation algorithm which distributes input sets from multiple sources to different output categories.

Counterfactual Explanations for Optimization

Marc Goerigk[1], Jannis Kurtz[2], Sebastian Merten[1]
[1]University of Passau, Germany; [2]University of Amsterdam, Netherlands; sebastian.merten@uni-passau.de

In addition to the quality of predictions, there is an increasing focus on the explainability of the models used in artificial intelligence. This is in response to the growing desire for transparency regarding the decision criteria used and their weighting. The acceptance of the results is thereby ensured. In the field of mathematical optimization, there is also increasing research into methods that guarantee explainability. A concept that is mainly used in machine learning is the use of so-called counterfactual explanations (CE). In the context of optimization, a CE describes the extent to which an instance would have to be changed such that an optimal solution fulfills a set of criteria. Currently, there is no practicable approach for generating CEs for general MIPs.

In our work, we want to investigate to what extent it is possible to generate CEs that are valid for the given optimization problem by using an approximation of the solution process. For a given optimization problem, we train a set of decision trees that map problem instances to solutions. We examine the trees that map to the desired solution and compute CEs based on their structure. The generated explanations are examined with respect to the original problem. First computational results are presented. The quality of the generated explanations and the runtime of our approach are discussed.

OR for Everyone: Solving OR Problems as Non-Experts with Generative AI

Jörn Maurischat[1], Stephan Bogs[2], Grit Walther[2], Olaf Kirchhof[1]
[1]Deutsche Bahn AG; [2]Chair of Operations Management, School of Business and Economics, RWTH Aachen University, 52072 Aachen, Germany; joern.maurischat@t-online.de

The great potential of mathematically sophisticated OR methods is currently not being fully utilized, as their application is limited to too few contexts and a shortage of trained experts. Furthermore, decision-making is not as evidence based as it could be, given the vast amount of data and analytical tools available. Using generative AI, the lack of expert skill may become less of a limiting factor in the use of advanced analytics. However, the risk of incorrect models and solutions needs to be assessed.

Our work examines the potential of generative AI to allow a broader audience access to linear programming (LP) techniques, enabling individuals without a significant background in mathematical programming to design, modify, and comprehend basic optimization models with minimal educational effort. We conducted a small laboratory study with management consultants of Deutsche Bahn. We provided them only a short introduction into building optimization models with ChatGPT, and then assessed their ability to solve optimization problems of various complexity.

The results indicate that participants could successfully deploy LP solutions to straightforward problems, suggesting a reduction in the entry barrier to using LP. Nevertheless, the efficacy of the generative AI support decreased as the task complexity increased, thereby increasing the risk of undiscovered incorrect solutions. While these findings indicate the potential for greater accessibility, they also highlight the potential risks of incorrect implementations and solutions by non-experts.

TC 06: Applications of Combinatorial Optimization 2

Time: Thursday, 05/Sept/2024: 11:30am - 1:00pm · *Location:* Wirtschaftswissenschaften Z534
Session Chair: Bjørn Petersen

The Sales Force Deployment Problem with Modular Capacities and Capacity-Dependent Sales Elasticities

Sven Müller, Lorena Silvana Reyes Rubiano, Lucas Weber

RWTH Aachen University, Germany; reyes@analytics.rwth-aachen.de

This study explores the sales force deployment problem, focusing on profit-maximizing through four main areas: setting the optimal salesforce size, assigning salesperson locations, designing sales territories, and managing resource allocation. We employ a concave sales response function based on the premise that sales efficiency decreases as more resources are expended, specifically referencing the critical resource of salesperson time devoted to accounts. Our model incorporates an infinite number of binary variables to represent a point of selling time in a continuous time interval. Extending upon Haase & Müller (2014) branch-and-price algorithm by allowing sales territories to be handled by sales teams instead of only one sales representative.

We analyze the fixed costs associated with various sales team sizes within specific sales coverage units, investigating how the sales function effectiveness changes with sales team size due to time elasticity. The objective is to maximize overall profit from all sales representatives across their territories. This approach enhances our understanding of sales coverage by examining the impact of sales force composition and the strategic distribution of sales territories. We present preliminary numerical results that light the relationship between sales team size and revenue fluctuations, guided by different parameters for time elasticity.

The Electric Hazmat Transport Network Design Problem

Vladimir Stadnichuk, Grit Walther

RWTH Aachen, Germany; vladimir.stadnichuk@om.rwth-aachen.de

We examine the Hazmat Transport Network Design Problem (HNDP), a well-researched bilevel problem in network design featuring linking interdiction constraints, where the first level of decision-making is governed by authorities and the second level by truck drivers transporting hazardous goods. The authorities can forbid certain streets for hazmat transport, and the truck drivers react by selecting the shortest path that adheres to these restrictions. The objective for the authorities is to forbid roads such that the drivers are guided towards less risky roads. We propose a novel extension by incorporating electric vehicles at the second level, which transforms the second level problem into a non-convex one. To solve the resulting bilevel problem, we develop a novel cutting plane procedure that merges Dantzig-Wolfe with Benders decomposition. Analogous to the well-known results for the case with a convex follower, we show that the underlying Benders subproblem can be decomposed into two subproblems, where the first represents the leader's problem conditional on the follower's reaction, and the second corresponds to the follower problem with a penalty term. We introduce additional speed-up techniques, such as partial decomposition and Pareto-optimal cuts, enhancing the efficacy of our methodology. In a preliminary computational analyses, we compare our approach with the standard Benders-like technique from the literature.

Minimizing the Airplane Boarding Time by Passenger-Seat Assignments

Felix J. L. Willamowski

RWTH Aachen University, Germany; willamowski@or.rwth-aachen.de

Airline passengers usually have their seats selected or assigned before arriving at the gate in the airport. We investigate the impact of the passenger-seat assignment on the boarding completion time, especially when considering a central decision-making process that takes place when passengers are already in line. Different seat assignments may result in different boarding completion times, which directly influence the turn-around time of an airplane. Identifying seat assignments that minimize boarding time can therefore provide airlines with significant cost savings. We introduce the problem of assigning passengers to seats while minimizing boarding time in the context of combinatorial optimization, study the computational complexity of the problem and develop exact, approximation, and heuristic algorithms. In addition to a theoretical analysis, we compare these algorithms in a computational study. Furthermore, we investigate an online variant of assigning passengers to seats—proposed in Jaehn and Neumann's section on future research—and present results on the competitive ratio.

Flowty's resource constrained shortest path algorithm

Bjørn Petersen, Simon Spoorendonk

Flowty, Denmark; bjorn@flowty.ai

Flowty is a network optimisation solver that exploits the network structure in a column generation algorithm. This talk is about the resource constrained shortest path (RCSPP) algorithm at the core of this algorithm.

The RCSPP algorithm is a bidirectional labeling algorithm parallelised on a bucket level, that is pulling (as opposed to pushing) labels into buckets. The sizes of the buckets are small enough to avoid cycles within the bucket.

Pulling into buckets is done in parallel for independent buckets. The dependency graph between buckets is handled implicitly, and the bidirectional midpoint/stopping criteria is dynamic, meaning that buckets are extended until the opposite direction is encountered.

As is always the case for pull-based labeling algorithms; carefully choosing the order of which labels are created, it is possible to guarantee that only labels not dominated are ever stored. This not only limits the memory footprint, it also allows labels to be stored as immutable 'object of arrays' (as opposed to 'array of objects') thereby enabling the use of vectorised instructions for dominance checks and thus exploiting a second level of parallelisation.

The Vehicle Routing Problem with Time Windows (VPRTW) is used as an illustrative case.

TC 07: Theory of Combinatorial Optimization 2

Time: Thursday, 05/Sept/2024: 11:30am - 1:00pm · *Location:* Wirtschaftswissenschaften Z536
Session Chair: Shai Michael Dimant

On the empirical hardness of the unrelated parallel machine scheduling problem

Akram Badreddine Laissaoui[1], Amine Athmani[4], Taha Arbaoui[1], Maximilian Schiffer[2,3]

[1]INSA Lyon, Université Lumière Lyon 2, Universite Claude Bernard Lyon 1, Université Jean Monnet Saint-Etienne, DISP UR4570, 69621Villeurbanne, France; [2]School of Management, Technical University of Munich, Germany; [3]Munich Data Science Institute, Technical University of Munich, Germany; [4]University of Technology of Troyes; taha.arbaoui@insa-lyon.fr

Hardness of optimization problems has been studied for several decades both theoretically and empirically. In this context, empirical hardness revolves around the observation that the computational tractability of an NP-hard problem can vary significantly between instances depending on their characteristics, even if they are of similar size. Understanding which characteristics drive this computational tractability is of interest from a practical perspective as it can allow to preselect a suitable class of algorithms without investigating significant methodological development or implementation effort.

Against this background, this work tackles the empirical hardness of unrelated parallel machine scheduling problems. First, we introduce a novel hardness measure to quantify the empirical hardness entailed by certain data patterns of an instance. The measure is based on run time, number of cuts explored, and the relative gap of an exact solver within a time limit. Existing benchmark instances are then analyzed and studied to identify the hardness of each instance. Next, a deep descriptive study follows to define complementary order parameters that govern the empirical hardness produced by the resulting instance. We show that the newly generated benchmark contains a higher number of hard instances highlighting the efficiency of the proposed instance generation protocol. Moreover, we introduce a machine-learning-based predictor and show that it efficiently predicts the hardness of instances.

Primal Separation and Approximation for the {0, 1/2}-closure

Lukas Brandl, Andreas S. Schulz

Technische Universität München, Germany; lukas.brandl@tum.de

We advance the theoretical study of {0, 1/2}-cuts for integer programming problems. Such cuts are Gomory-Chvátal cuts that only need multipliers of value 0 or 1/2 in their derivation. The intersection of all {0, 1/2}-cuts derived from the inequality description is called the {0,1/2}-closure of the polytope P.

The primal separation problem for {0, 1/2}-cuts is: Given a vertex of the integer hull of P and some fractional point in P, does there exist a {0,1/2}-cut that is tight at the integral vertex and violated by the fractional point? Primal separation is the key ingredient of primal cutting-plane approaches to integer programming. In general, primal separation for {0,1/2}-cuts is NP-hard. We present two cases for which primal separation is solvable in polynomial time. As an interesting side product, we obtain a(nother) simple proof that matching can be solved in polynomial time.

Furthermore, since optimization over the Gomory-Chvátal closure is also NP-hard, there has been recent research on solving the optimization problem over the Gomory-Chvátal closure approximately. In a similar spirit, we show that the optimization problem over the {0,1/2}-closure can be solved in polynomial time up to any fixed precision.

Interdicting matroids with parametric weights

Nils Hausbrandt, Stefan Ruzika

RPTU Kaiserslautern, Germany; nils.hausbrandt@math.rptu.de

In this talk, we introduce the parametric matroid l-interdiction problem, where l is a fixed natural number. Given a matroid where each element has a parametric weight that depends linearly on a real-valued parameter from a parameter interval, the goal is to compute for every possible parameter value an optimal interdiction strategy. An optimal interdiction strategy is a set of l elements that when removed from the matroid increases the weight of the minimum weight basis as much as possible. The problem can be viewed as a parametric and thus robust extension of the matroid l-interdiction problem, which is a well-studied problem for the special case of graphical matroids. We show different properties of an optimal interdiction strategy to reduce the number of relevant strategies. We further use these properties to construct an exact algorithm to solve the problem in polynomial time.

On Applications of Partial Scenario Set Cover

Shai Michael Dimant, Sven O. Krumke

RPTU Kaiserslautern-Landau, Germany; shai.dimant@math.rptu.de

The Partial Scenario Set Cover problem (PSSC) generalizes the Partial Set Cover problem, which is itself a generalization of the classical Set Cover problem. We are given a finite ground set Q, a collection S of subsets of Q to choose from, each of which is associated with a nonnegative cost, and a second collection U of subsets of Q of which a given number l must be covered. The task is to choose a minimum cost sub-collection from S that covers at least l sets from U. The motivation behind PSSC stems from its application in locating emergency doctors. We explore several graph-theoretic problems within the framework of PSSC. We demonstrate that these problems are as hard to approximate as the Smallest k-Edge Subgraph problem. Additionally, we present simple approximation algorithms tailored to address these challenges. Our findings not only shed light on the inherent difficulty of these problems but also provide practical solutions for their approximation.

TC 08: Optimal Control Applications II

Time: Thursday, 05/Sept/2024: 11:30am - 1:00pm · *Location:* Wirtschaftswissenschaften Z538
Session Chair: Florian Bürgel

Discrete-continuous optimization in Data-Driven Computational Mechanics

Cristian G. Gebhardt[1], Senta Lange[2], Marc C. Steinbach[2]

[1]University of Bergen; [2]Leibniz Universität Hannover, Germany; mcs@ifam.uni-hannover.de

Data-Driven Computational Mechanics (DDCM) is a recent paradigm in continuum mechanics simulations

where the empirical material law that describes elasticity is replaced by a minimum-distance requirement with respect to raw measured data. We present function space formulations and finite element discretizations of the problem and analyze their properties, particularly the existence and uniqueness of solutions. We also discuss structure-exploiting algorithmic approaches for solving the problem in the function space setting and in the discretized setting.

Computing the Viability Kernel using Constrained Polynomial Zonotopes

Sigifredo Laengle, Tomás Laengle-Aliaga

University of Chile, Chile; slaengle@fen.uchile.cl

Efficient set representation is the most relevant challenge of viability kernel numerical computation. Indeed, the classical Saint-Pierre (forward Euler) algorithm shows an accelerated explosion, even in reduced dimensions, attributed to its grid-based representation. On the other hand, in the context of the reachability problem, some authors have recently proposed the representation of (nonconvex) sets based on constrained polynomial zonotopes (CPZ). Since the issues of viability and reachability are closely related, the question arises about the effectiveness of the CPZ representation in computing the viability kernel. Therefore, we compare algorithms based on the CPZ representation with the classical Saint-Pierre representation. Additionally, we implemented the viability algorithm in its forward and backward versions using the CPZ representation. In this work, we found that the CPZ-based method is less demanding of computational resources. However, this comes at the cost of the accuracy of the results. Although our calculations are promising, we urgently propose investigating the error estimation of viable sets based on the CPZs representation.

Potential of dynamic wind farm control by axial induction in the case of wind gusts

Florian Bürgel[1], Robert Scholz[2], Christian Kirches[1], Sebastian Stiller[1]

[1]TU Braunschweig, Institute for Mathematical Optimization, Germany; [2]University of Heidelberg, Interdisciplinary Center for Scientific Computing, Germany; f.buergel@tu-braunschweig.de

Each wind turbine causes a wake with a reduced wind speed. This wake influences the mechanical loads and power of downstream turbines. Therefore, there is a strong interaction between the individual wind turbines in a wind farm. This interaction is an opportunity for optimal control to minimize the total load (e.g., tower activity) while increasing or keeping the total power of a wind farm, in particular in case of a wind gust as it requires a dynamic control reaction. We use the already known axial-induction-based control and investigate its potential using optimization in the case of a simply modeled wind gust in a turbulent wind field that passes through a simulated wind farm consisting of two turbines. First, for an initial guess, we modify the reaction of a standard controller by a heuristic. Second, knots and values of a cubic spline interpolation based on the initial guess offer the possibility to solve an optimization problem by sequential quadratic programming (SQP). We show that dynamic control of the upstream turbine significantly reduces the tower activity of the downstream wind turbine and finally reduces the total tower activity.

TC 09: Network Revenue Management

Time: Thursday, 05/Sept/2024: 11:30am - 1:00pm · *Location:* Wirtschaftswissenschaften Z532
Session Chair: Claudius Steinhardt

Revenue management without demand forecasting: a data-driven approach for bid price generation

Jonas Rauch
PROS; jrauch@pros.com

We present a data-driven approach to RM which eliminates the need for demand forecasting and optimization techniques. We develop a methodology to generate bid prices using historical booking data only. Our approach is an ex-post greedy heuristic to estimate proxies for marginal opportunity costs as a function of remaining capacity and time-to-departure solely based on historical booking data. We utilize a neural network algorithm to project bid price estimations into the future. We conduct an extensive simulation study where we measure our methodology's performance compared to that of an optimally generated bid price using dynamic programming (DP) and compare results in terms of both revenue and load factor. We also extend our simulations to measure performance of both data-driven and DP generated bid prices under the presence of demand misspecification. Our results show that our data-driven methodology stays near a theoretical optimum (< 1% revenue gap) for a wide-range of settings.

Stochastic Hidden Convex Optimization and Applications in Network Revenue Management

Xin Chen[3], Niao He[2], Yifan Hu[1,2], Zikun Ye[4]
[1]EPFL, Switzerland; [2]ETH Zurich, Switzerland; [3]Gatech, US; [4]U Washington, US; yifan.hu@epfl.ch

We study a class of stochastic hidden nonconvex optimization arising from revenue management. Leveraging the implicit convex reformulation (i.e., hidden convexity), we develop stochastic gradient-based algorithms and establish their sample and gradient complexities for achieving global optimal solutions for the nonconvex problem. Interestingly, our proposed Mirror Stochastic Gradient (MSG) method operates only in the original space using gradient estimators of the nonconvex objective and achieves sample complexities, that matches the lower bounds for solving stochastic convex optimization problems. In air-cargo network revenue management, extensive numerical experiments demonstrate the superior performance of our proposed MSG algorithm for booking limit control with higher revenue and lower computation cost than state-of-the-art bid-price-based control policies.

TC 10: Patient Transportation

Time: Thursday, 05/Sept/2024: 11:30am - 1:00pm · *Location:* Wirtschaftswissenschaften 0514
Session Chair: Isabel Wiemer

Modelling patient transportation in hospitals: A Multiple Travelling Salesperson approach with Time Windows using Column Generation and Heuristics

Corinna Oppitz[1], **Jens O. Brunner**[1,2]

[1]University of Augsburg, Germany; [2]Technical University of Denmark, Denmark; corinna.oppitz@uni-a.de

A well-structured patient transportation service in hospitals is not only crucial for meeting patients' appointments in time but could also help a hospital to reduce overtime as well as idle time in costly areas. In this work, the "patient transportation problem" is modelled as a Multiple Travelling Salesperson Problem with Time Windows. By assigning a node to every transportation request, time windows referring to the associated medical appointment can be incorporated, whereas the salespersons represent the staff of the hospital's inner clinical transportation service. In order to improve the staff's well-being, the objective is to balance the workload of these employees. Due to complexity reasons, two different column generation approaches in combination with a greedy heuristic are used to create upper and lower bounds, which are compared in a computational study. The column generation algorithms differ in the subproblem and its solution process: In the first approach, the subproblem is an Elementary Shortest Path Problem with Time Windows, which is solved using a standard solver. In the second approach, the relaxed version of the subproblem, the Shortest Path Problem with Time Windows (SPPTW), is solved using a labelling algorithm, but the tours are made elementary afterwards. Real world data of about one year is provided by the University Hospital Augsburg. First results for randomly picked real-world transportation requests show a clearly superior runtime of the column generation algorithm that solves the SPPTW as a subproblem and a good performance of the greedy heuristic.

Impact of Crew Availability on Home Health Care Routing Problem with Time Windows

Nozir Shokirov[1,2], **Tonguç Ünlüyurt**[2,3], **Bülent Çatay**[2,3]

[1]Schenker AG, Essen, Germany; [2]Sabanci University, Faculty of Engineering and Natural Sciences, Istanbul, Turkey; [3]Smart Mobility and Logistics Lab, Sabanci University, Istanbul, Turkey; nozir.shokirov@dbschenker.com

Due to the ever-growing demand for home healthcare (HHC) services, optimizing the routing and scheduling decisions in HHC is crucial to efficiently utilize the limited resources and deliver high-quality care to patients. One of the biggest challenges in HHC is the shortage of healthcare personnel, especially during periods when traditional healthcare institutions are overloaded (i.e., COVID-19) and more people try to avoid going to hospitals and prefer to get treatment at home. In this study, we investigate the effect of different limits on health care personnel availability on small instances adapted from the literature with various scenarios by solving these instances optimally. The trade-off between decreasing the number of personnel and the corresponding increase in the traveled distance is explored. Moreover, we generate larger instances and analyze the coverage percentage of patients with varying available staffing capacities.

A Bi-Objective Covering Location Model for Improving Fairness in Emergency Medical Service Systems

Isabel Wiemer, **Jutta Geldermann**

University Duisburg-Essen, Germany; isabel.wiemer@uni-due.de

Emergency medical service (EMS) has to respond quickly and efficiently to all emergencies within a considered area. However, especially in areas with heterogeneous demand distribution like urban, mixed and rural areas, the level of coverage can vary widely. To reduce inequalities in coverage, many approaches take into account fairness as model objective by explicitly addressing the coverage of the worst-covered area. Thereby, the coverage levels of the second, third etc. worst-covered areas are not directly addressed.

Therefore, we propose to maximize the average expected coverage of the set p of worst covered areas. Our fairness objective explicitly considers the second, third etc. worst-covered area and aims to improve not only the coverage level of the worst-covered area, but the average coverage level of the set p of worst-covered areas. We combine our novel fairness objective with expected coverage to a bi-objective optimization model using the epsilon constraint method. In that way, we aim at maintaining an acceptable level of overall coverage. Our model's applicability is analyzed at hand of a real-world case study for the city of Duisburg (Germany). We examine different levels of overall coverage to analyze the influence on the individual coverage levels of the different areas. First results show that the proposed fairness model can improve the average coverage of the set p of worst-covered areas without giving up too much efficiency.

TC 11: Auctions

Time: Thursday, 05/Sept/2024: 11:30am - 1:00pm · *Location:* Theresianum 2609
Session Chair: Matthias Oberlechner

Share and Cash Auctions in Procurement

Nicolas Fugger

Uni Köln, Germany; fugger@wiso.uni-koeln.de

Procurement managers have various payment schemes available when awarding contracts to suppliers. Among these, cash auctions are the most commonly used type of procurement auction. In a cash auction, the contract is awarded to the supplier who bids the lowest cash amount for the project. This method is straightforward and easily comparable across different bids, making it a preferred choice in many scenarios.

Another option available to suppliers is to propose a profit-sharing model in what is known as a share auction. Here, instead of a fixed cash payment, suppliers request a percentage of the profits generated from the project they are involved in.

In our project, we provide a theoretical and experimental analysis of share and cash auctions. The theoretical analysis shows that share auctions lead to better buyer outcomes, i.e., lower prices. Furthermore, it shows that the buyer should specify a high project value in the contract to foster competition.

Our experimental data substantiates the theoretical predictions. We observe that cash auctions yield lower prices than cash auctions. This effect is stronger, when the buyer specifies a high project in the contract. Even though share auctions may appear more complex, we do not find any difference in efficiency.

Low Revenue in Display Ad Auctions: Algorithmic Collusion vs. Non-Quasilinear Preferences

Martin Bichler[1], Alok Gupta[2], Laura Mathews[1], Matthias Oberlechner[1]

[1]Technical University of Munich, Germany; [2]University of Minnesota, USA; matthias.oberlechner@tum.de

The transition of display ad exchanges from second-price to first-price auctions has raised questions about its impact on revenue, but evaluating these changes empirically proves challenging. Automated bidding agents play a significant role in this transition, often employing dynamic strategies that evolve through exploration and exploitation rather than using the static game-theoretical equilibrium strategies. Thus revenue equivalence between first- and second-price auctions might not hold.

Research on algorithmic collusion in display ad auctions found that first-price auctions can induce Q-learning agents to tacitly collude below the Nash equilibrium, which leads to lower revenue compared to the second-price auction.

Our analysis explores widespread online learning algorithms' convergence behavior in both complete and incomplete information models but does not find systematic deviance from equilibrium behavior. Convergence for Q-learning depends on hyperparameters and initializations, and algorithmic collusion also vanishes when Q-learning agents are competing against other learning algorithms.

The objective of bidding agents in these auctions is typically to maximize return-on-investment or return-on-spend, but not necessarily payoff maximization. The revenue comparison under such utility functions is an open question.

Analytical derivations of equilibrium are challenging, but learning algorithms allow us to approximate equilibria and predict the outcome when agents have such non-quasilinear objectives.

Our analysis shows that if learning agents aim to optimize such objectives rather than payoff, then the second-price auction achieves higher expected revenue compared to the first-price auction. Understanding the intricate interplay of auction rules, learning algorithms, and utility models is crucial in the ever-evolving world of advertising markets.

TC 12: Multi-criteria Optimization

Time: Thursday, 05/Sept/2024: 11:30am - 1:00pm · *Location:* Theresianum 2601
Session Chair: Michael Stiglmayr

The violation of the monotonicity condition under the assumption of weak disposability

Alexander Schnabl

Vienna University of Economics and Business, Austria; di.alexander.schnabl@chello.at

The Data Envelopment Analysis (DEA) was initially developed for multidimensional output production processes wherein prices as valuation system are (partially) unavailable. Different DEA models were presented later, which also consider undesirable outputs (bads) of production. The most prevalent approach incorporating bads into these models is the assumption of weak disposability regarding these bads. One drawback of this approach is the potential violation of the monotonicity condition, which could lead to possible misclassifications of efficient and inefficient units and incorrect efficiency values. Unlike other constraints in DEA, weak disposability is represented by equations. As is generally known, the shadow prices in the dual program can now accept any sign and can be negative. If the bad increases, the eco-efficiency value will also increase, with negative associated shadow prices. This implausible phenomenon is examined, including the (economic) conditions that facilitate its occurrence, the data structure depending on the relations between inputs, outputs and bads, and its implications for the presentation of eco-DEA models and their outcomes. Furthermore, it is demonstrated that these models are related to the More-for-less paradox in linear programming in specific instances. Sufficient conditions for identifying units for which this phenomenon occurs are presented. Beyond that, it is demonstrated that under the weak disposability assumption the efficiency frontier changes with the orientation of the DEA model, in contrast to the standard DEA models; this result is also applicable to detection of such units.

A Novel Reduction Approach to Bi-level Multi-criteria Optimization Problems

Mara Schubert, Katrin Teichert

Fraunhofer Institute for Industrial Mathematics ITWM, Germany; mara.schubert@itwm.fraunhofer.de

Solving bi-level multi-criteria optimization problems is a complex endeavor. The lower-level optimization problem can create a complex feasible set for the upper-level problem. Even when bi-level problems are structured to allow for the independent consideration of one level, as is the case with lexicographic methods, the multi-criteria nature of these issues can still create difficulties.

Our focus is on hierarchical bi-level multi-criteria optimization problems, in particular those where the lower-level is independent, and the upper-level objectives do not depend on the lower-level variables. This problem class encompasses reoptimization problems where, subsequent to the initial optimization, secondary criteria need to be taken into account without compromising the quality of the initially optimized goals.

We demonstrate a method to transform hierarchical bi-level problems into equivalent single-level multi-criteria problems, by creating a fitting domination cone. The resulting single-level reduction has the same Pareto front as the bi-level problems' optimistic solutions. This facilitates the application of standard multi-criteria optimization (MCO) methods, including the approximation of the entire Pareto front to a predefined accuracy and the navigation on it. Furthermore, we give an outlook on how the presented method can be iteratively applied to multi-level MCO problems, effectively simplifying them into single-level MCO problems.

Multiobjective Branch and Bound and the Effectiveness of Branching and Queuing Strategies

Michael Stiglmayr[1], Julius Bauß[1], Sophie Parragh[2]

[1]University of Wuppertal, Germany; [2]Johannes Kepler University Linz, Austria; stiglmayr@uni-wuppertal.de

Multiobjective branch and bound has gained quite some attention during the last few years. Despite this fact objective space methods are still the gold standard for general multiobjective integer programming problems, while multiobjective branch and bound algorithms are only competitive in specific situations. Multiobjective branch and bound algorithms run into difficulties as the size of the upper and the lower bound set can grow exponentially with the number of objective functions. Moreover, the higher the number the objective functions is, the weaker are the corresponding bounds in general. Therefore, a suitable branching and queuing strategy is of high importance. Thereby it is crucial not only to find efficient solutions in early stages of the algorithm but also to find a set of solutions whose images are close to and well distributed along the non-dominated frontier.

The adaptive use of objective space information can guide the search in promising directions to determine a good approximation of the Pareto front already in early stages of the algorithm. In particular we focus in this article on improving the branching and queuing of subproblems and the handling of lower bound sets. In our numerical test we evaluate the impact of the proposed methods in comparison to a standard implementation of multiobjective branch and bound on knapsack problems, generalized assignment problems and (un)capacitated facility location problems.

TC 13: Modeling

Time: Thursday, 05/Sept/2024: 11:30am - 1:00pm · *Location:* Theresianum 2605
Session Chair: Muhammet Soyturk

Gurobi OptiMods

Marika Karbstein

Gurobi Optimization, Germany; marika.karbstein@gurobi.com

One of the most important aspects of mathematical optimization and Operations Research is getting your data into a form that optimization solvers can understand and work with. The "art of modeling", as it is often referred to, can all too easily get in the way of actually solving the problem at hand.

Gurobi's open-source OptiMods are data-driven Python APIs for common optimization use cases. They enable practitioners and learners to compute solutions without requiring extensive modeling experience. This session presents the project's goals and design and explains how to use and extend it.

Flowty - A Network Optimisation Solver

Simon Spoorendonk, Bjørn Petersen

Flowty, Denmark; simon@flowty.ai

Network optimization problems are recognised by their underlying graph(s) and constraints. Examples are within planning & scheduling, vehicle routing, and multi-commodity flow problems. Flowty's solver exploits the graph structure and solves resource constrained shortest path problems to generate variables using a column generation scheme.

Graphs are described as edge sets and a source and target vertices for a path. Paths can additionally be constrained with a set of resources. Constraint modeling is done directly on the vertices and edges of the graphs, the subproblem itself, as well as on traditional mixed integer variables. This allows for very compact models, e.g., set partitioning constraints on vertices and edge design variables in network design problems, and the graph and resource constraints avoids the need for linearisation of constraints (big-M).

The literature has shown that column generation based algorithms are superior for many network optimization problems. The solver combines the familiarity of mixed integer programming models and graph structures with algorithmic speed.

In this talk we will dive into modeling examples in Python, take a quick look under the hood, and present recent performance benchmarks.

Modeling large optimization problems with Hexaly

Julien Darlay

Hexaly, France; jdarlay@hexaly.com

Hexaly is a new kind of global optimization solver that combines exact and heuristic methods designed to tackle large-scale industrial problems. Several approaches have been developed by the operations research community to solve these large problems (e.g., heuristics, column generation, model decomposition, etc.). One of the main challenges for a model & run solver is to offer a modeling formalism, both generic and sparse. The genericity ensures that most of the problems can be modeled in the formalism while the sparsity ensures that the model stays linear in the size of the input. While SAT and MIP formalisms offer genericity, certain models require a quadratic or an exponential number of decisions and constraints (e.g. traveling salesman problem, bin packing or scheduling). Conversely, CP models offer global constraints that ensure sparsity but may lack genericity (e.g. non overlap with complex setup times for instance). To overcome these issues, Hexaly added set-based models to its formalism. Intervals, sets and lists can be used as decision variables and functions can be used to derive numerical expressions that can later be constrained or optimized. Vehicle routing problems, scheduling problems and most variants of bin packing can be easily modeled with a combination of sets, lists and intervals. The resolution of these problems is done using heuristics and exact techniques. This presentation will describe Hexaly models for packing, routing, and scheduling and give benchmark results on large instances with hundreds of thousands of items, clients, or tasks.

GAMSPy - Where Convenience of Python Meets GAMS' Performance

Muhammet Soyturk, Justine Broihan

GAMS, Germany; msoyturk@gams.com

OptimIzation pipelines contain many tasks such as mathematical modeling, data processing, and developing algorithms. Python and its vast array of packages provide a convenient way of data gathering, pre/post-processing of the data, the visualization of the data and developing necessary algorithms by utilizing existing ones. On the other hand, GAMS has been providing tools with great performance for the mathematical modeling part for decades. In this talk, we will talk about a new tool GAMSPy that aims to combine the best of both worlds.

TC 14: Innovation and Technology in Industry

Time: Thursday, 05/Sept/2024: 11:30am - 1:00pm · *Location:* Theresianum 2607
Session Chair: Anne Kißler

Real-World Business Challenges and Their Impact on the Design of Heuristics in the Development of Standard Supply Chain Software

Anne Kißler
SAP SE, Germany; anne.kissler@sap.com

The challenges faced in the design of heuristics for standard supply chain software are highlighted. Using the capacitated vehicle routing problem with time windows (CVRPTW) as an example, it is shown which additional business constraints need to be incorporated into the problem formulation, and how to address the impact of software product standards on algorithm design and architecture.

Machine Learning Based Decomposition Strategies for Solving Rich Vehicle Routing Problems

Christoph Kerscher, Stefan Minner
Technical University of Munich, Germany; christoph.kerscher@tum.de

Several metaheuristics use decomposition and pruning strategies to solve large-scale instances of the vehicle routing problem (VRP). Those complexity reduction techniques often rely on simple, problem-specific rules. However, the growth in available data and advances in computer hardware enable data-based approaches that use machine learning (ML) to improve scalability of solution algorithms. We propose a decompose-route-improve (DRI) framework that groups customers using clustering. Its similarity metric incorporates customers' spatial, temporal, and demand data and is formulated to reflect the problem's objective function and constraints. The resulting sub-routing problems can independently be solved using any suitable algorithm. We apply pruned local search (LS) between solved subproblems to improve the overall solution. Pruning is based on customers' similarity information obtained in the decomposition phase. We parameterize and compare the clustering algorithms in a computational study and benchmark the DRI against state-of-the-art metaheuristics. Results show that our data-based approach outperforms classic cluster-first, route-second approaches solely based on customers' spatial information. The introduced similarity metric forms separate sub-VRPs and improves the selection of LS moves in the improvement phase. Thus, the DRI scales existing metaheuristics to achieve high-quality solutions faster for large-scale VRPs by efficiently reducing complexity. Further, the DRI can be easily adapted to various solution methods and VRP characteristics, making it a generalizable approach to solving routing problems.

Importance of Academic Research for Standard Logistics Software

Tobias Mueller, Rüdiger Eichin
SAP SE, Germany; tobias.mueller15@sap.com

Academic research plays a critical role in innovating and shaping the future of standard logistics software. As exemplified by the SAP@TUM collaboration, we highlight the pivotal role of collaborative, applied research and how partnering with academia drives product innovation. We provide insights into the SAP@TUM collaboration model, its underlying operational structure, and project workflow. Based on an exemplary project, we showcase how industry-university collaborations impact standard logistics software and lead to enhanced results regarding performance, solution quality, and innovative modeling approaches. These advancements ultimately deliver significant value to customers, setting the stage for future innovations.

TC 15: Green Supply Chains

Time: Thursday, 05/Sept/2024: 11:30am - 1:00pm · *Location:* Wirtschaftswissenschaften 0534
Session Chair: Eberhard Schmid

Modelling Diversification of Import Networks for Green Hydrogen

Louis Vincent Sroka, Frank Meisel

Christian-Albrechts-University of Kiel, Germany; vincent.sroka@bwl.uni-kiel.de

‘Green hydrogen’ is a promising alternative to fossil fuels that can potentially decarbonize the future transport and energy sectors. But a sustainable energy economy based on green hydrogen is limited by the availability of resources (feedstock) and production capacities in many countries. The discrepancy between high demand and low self-supply leads to the necessity of a compensation through imports from other regions of the world. However, an overreliance on a single exporting nation should be avoided since this can lead to geopolitical, financial, and moral complications. The sustainable import of green hydrogen should be diversified instead. Rather than only relying on parallel bilateral imports, a multinational transportation network offers the potential for cost reduction through consolidation in production, conversion, and transportation. We propose an optimization model for such a multinational import network for green hydrogen, that considers import diversification as well as factors like transportation losses and conversion efficiencies. Using Germany as a case study, we demonstrate how enforced diversification impacts sourcing decisions and overall costs to further emphasize the trade-off between resilience and cost-effectiveness. Furthermore, we highlight how the optimal transport network changes and hydrogen prices can be further reduced with smaller losses of liquified hydrogen during transportation.

Robust optimization of a renewable fuel supply chain network under uncertain demand

Mina Farajiamiri, Grit Walther

Chair of Operations Management, RWTH Aachen University, Germany; mina.amiri@om.rwth-aachen.de

Renewable fuels aim at reducing greenhouse gas emissions in transportation applications that cannot be electrified (such as long-haul trucks, aviation, and shipping). Besides the challenges posed by the long-term planning horizon as required for net zero emissions scenarios and the seasonal availability of the required resources like biomass and electricity generated by solar and wind power, renewable fuel supply chain planning is further complicated by uncertainties related to supply and demand fluctuations or uncertain technological developments. Thus, these renewable fuel supply chains need to be flexible and robust so that they can cope with uncertainties.

This study seeks to develop a robust model for optimizing the renewable fuel supply chain network regarding uncertain future fuel demand. Using Bertsimas and Sim's approach, a robust reformulation is applied to minimize the total cost of the supply chain. A number of factors are taken into account in this model, including long-term horizons, multiple periods, seasonality, multiple stages, and multiple conversion technologies. To evaluate the performance of the model, several random demand scenarios are considered over a long-term horizon, along with strategic investment and operational decisions. An analysis of the EU transport sector's transition to climate neutrality from 2020 to 2060 illustrates the effectiveness of this approach.

Bi-Objective Supply Chain Network Design with Transport Mode Selection

Eberhard Schmid

HWR Berlin, Germany; eberhard.schmid@hwr-berlin.de

In Supply Chain Network Design (SCND), the decision maker’s task is to decide upon locations for production or distribution facilities, product allocations to warehouses and factories, customer allocations and the choice of the transport modes. These decisions do not only have an impact on the economic performance of the supply chain but also on environmental indicators like the emission of CO2. To account for trade-offs, multi criteria SCND-modelling approaches are discussed increasingly.

In this paper, we will present a bi-objective SCND modelling approach which explicitly considers the selection of the mode of transport, as one possible leaver in the reduction of CO2. We model specific characteristics of transport modes, like the lead time and the shipment size and their influence on safety stock and cycle stocks. Through this, we are able to model trade-offs, which so far are not considered in the literature on multi criteria SCND-models. We describe a solution procedure, which includes the conversion into a mixed integer conic quadratic optimisation model, demonstrate the applicability within a case study and discuss computational and managerial insights. Further we give an outlook on the possible error supply chain decision makers can make, when ignoring those effects in the application of multi criteria SCND models.

TC 16: Material Handling / Warehousing

Time: Thursday, 05/Sept/2024: 11:30am - 1:00pm · *Location:* Wirtschaftswissenschaften 0540
Session Chair: Julian Golak

A General Model Formulation Applicable to the Premarshalling, Block Relocation and Stack Loading Problem

Alf Kimms, Fabian Wilschewski

University of Duisburg-Essen, Germany; fabian.wilschewski@uni-due.de

As space for storing items is frequently scarce, it is a common approach to store items directly on top of each other within stacks, e. g., in a container terminal. Such a storing system is space-saving, but at the expense of the drawback that not every item is accessible at any time. Whenever a required item is not the topmost of its stack, all items located above it must be relocated first by means of time-consuming operations.

In this talk, we address three typical combinatorial optimization problems associated with this type of storing system: the premarshalling problem which deals with presorting operations of the stored items, the block relocation problem and the stack loading problem which deal with unloading and loading operations, respectively. A novel mixed integer linear model formulation is proposed that is applicable to all three selected optimization problems with only minor adjustments. In addition to its flexibility, the proposed model contains significantly less decision variables than existing model formulations for the addressed problems. The results of computational experiments are given.

Introducing combi-stations in robotic mobile fulfilment systems: A queueing-theory-based efficiency analysis

Lin Xie, Sonja Otten

University of Twente, The Netherlands; s.otten@utwente.nl

In the era of digital commerce, the surge in online shopping and the expectation for rapid delivery have placed unprecedented demands on warehouse operations. The traditional method of order fulfilment, where human order pickers traverse large storage areas to pick items, has become a bottleneck, consuming valuable time and resources. Robotic Mobile Fulfilment Systems (RMFS) offer a solution by using robots to transport storage racks directly to human-operated picking stations, eliminating the need for pickers to travel.

We present a new type of station, called combi-station, that enables both item picking and replenishment, as opposed to traditional separate stations. To analyse the efficiency of using combi-stations, we model the RMFS as a semi-open queueing network and apply approximation methods.

Retrieval optimization in a warehouse with multiple input/output-points

Jan-Niklas Buckow[1], Marc Goerigk[2], Sigrid Knust[1]

[1]Osnabrück University, Germany; [2]University of Passau, Germany; jabuckow@uni-osnabrueck.de

Optimizing retrieval requests in warehouses is essential for maintaining a smooth flow of products. Most studies on warehouse retrieval optimization have considered no more than two input/output-points for product retrieval. In this talk, we consider different variants of a new stacker crane scheduling problem, where pallets have to be retrieved in a warehouse with multiple input/output-points. The goal is to minimize the total travel time of the stacker crane to perform all retrievals. The problem variants we consider require determining either the pallet retrieval sequence, the assignment of pallets to input/output-points, or both. We prove NP-hardness results and identify cases that can be solved in strongly polynomial time. Additionally, we propose transformations to the traveling salesman problem, enabling the application of a vast collection of existing solution techniques. Finally, in an extensive computational study, we compare different problem variants, assess their gain of optimization, and experimentally analyze the impact of various instance parameters.

Order Retrieval in Compact Storage Systems

Malte Fliedner, Julian Golak, Yagmur Gül, Simone Neumann

Universität Hamburg, Germany; julian.golak@uni-hamburg.de

To ensure quick access to stored items, there are different types of storage systems. A number of factors, including the physical size and weight of the items to be stored, the frequency of use and the available resources (such as space), determine which type of system is most suitable for a particular warehouse. In this presentation, we examine a new type of storage system that has received little scientific attention to date: Compact storage systems. Compact storage systems aim to achieve the highest possible space utilisation with limited storage space. Although such a warehouse saves space, the removal of items from compact storage systems is complex. Due to the dense arrangement, the storage units are often not directly accessible as they are covered by other units. These must first be moved or repositioned to create enough space to access the desired item. This leads to complex decision-making processes. As the repositioning of storage units consumes energy, efficient decision-making contributes directly to an energy-efficient storage system. This requires the development of algorithmic support systems that are able to calculate optimal retrieval strategies in a reasonable amount of time.

In this presentation, we provide an overview of the combinatorial optimisation problems underlying these extraction strategies. In addition, we provide insights into the computability and algorithmic approaches used to derive efficient solutions.

TC 17: Transport Scheduling under Limited Battery Capacity

Time: Thursday, 05/Sept/2024: 11:30am - 1:00pm · *Location:* Wirtschaftswissenschaften 0544
Session Chair: Alena Otto

Machine-learning-assisted matheuristic for the alternative fuel scheduling problem

Stefan Blackert, Simon Emde

Friedrich-Schiller-Universität Jena, Germany; stefan.blackert@uni-jena.de

This paper considers the scheduling of electric vehicles in a public transit system. The restriction on range of electric vehicles is alleviated by allowing charging stops in between consecutive service trips.

To solve this multiple depot vehicle scheduling problem, we develop a machine-learning-assisted matheuristic based on column selection. A machine-learning model is trained to predict whether a vehicle schedule is likely to be part of a good solution. We use the machine-learning model to decide which branch of an enumeration tree should be extended until a feasible solution is found. The optimal charging stops are then inserted into every created vehicle schedule using dynamic programming. A set partitioning model is formulated to choose the best subset of vehicle schedules and solved by applying Gurobi. We also use the machine-learning model to derive a simple decision rule to create a second heuristic approach that is fast enough to solve large instances of the AF-VSP. The algorithms are then tested on randomly generated data and a subset of a real world dataset extracted from the Berlin City Open Data Portal, containing 6,583 service trips. Both algorithms outperform a state-of-the-art literature heuristic.

The Truck-Drone Hurdle Relay Problem in the Euclidean Space

Christin Münch, Alf Kimms

University Duisburg-Essen, Germany; christin.muench@uni-due.de

The use of drones makes it possible to reach areas that are inaccessible by vehicles operating on the ground. However, the limited energy capacity of a drone’s battery limits its flight range. This drawback can be mitigated when the drone is carried by trucks to advantageous launching points and when the drone’s battery is exchanged along its way. We propose a MILP in the Euclidean space where one drone must reach a faraway target location and where on its way, it lands on moving trucks for a battery exchange. The objective is to reach the target location as early as possible. Furthermore, we consider the following aspects: obstacles with which the drone must not collide, a service time for the battery exchange and a drone energy consumption dependent on velocity.

Novel models and exact approaches for selected multi-trip routing problems in production and healthcare

Amir Hosseini, Marc Goerigk, Alena Otto, Luis Rocha

University of Passau, Germany; alena.otto@uni-passau.de

We consider two interesting variants of routing problems inspired by applications in manufacturing and healthcare, where vehicles must visit the depot multiple times.

The first, called Collection and Delivery problem of biomedical Specimens (CDSP), addresses healthcare logistics. In this problem, specimens (blood, plasma, urin etc.) collected from patients in doctor's offices are transported to a central laboratory for analysis. It involves multiple trips, time windows, a homogeneous fleet, and aims to minimize total completion time of delivery requests. We propose a two-index MIP that, when used with an off-the-shelf solver, outperforms both the state-of-the-art model and metaheuristic from the literature.

The second problem involves Autonomous Guided Vehicles (AGVs) that must perform a set of transport requests within the constraints of their battery capacity, necessitating regular battery swaps. This results in a parallel machine scheduling problem with job-dependent activity cycles and constant maintenance time, where the machines are AGVs, and maintenance time refers to the battery swap duration. For this problem, we introduce a novel MIP that surpasses existing state-of-the-art models. We also develop a logic-based Benders decomposition strengthened by valid inequalities, enabling to solve previously unsolved instances reported in the literature.

TC 18: Energy Flexibility 2

Time: Thursday, 05/Sept/2024: 11:30am - 1:00pm · *Location:* Theresianum 0601
Session Chair: Lorenz Alexander Saathoff

Optimization of energy systems via sector coupling

Kevin-Martin Aigner[1], Robert Burlacu[2], Frauke Liers[1], Florian Rösel[1]

[1]Friedrich-Alexander Universität Erlangen-Nürnberg, Germany; [2]University of Technology Nuremberg; kevin-martin.aigner@fau.de

The integrated simulation and optimization of various energy sectors - electricity, gas, heat, and transportation - will significantly advance Germany's energy system development, particularly at the regional level.

We introduce a time-expanded holistic optimization model for sector coupling, aimed at minimizing operational expenditures through strategies such as bidirectional electric vehicle charging and optimal control of heat pumps and electrolyzers. To address scalability challenges, we employ the rolling horizon approach as a decomposition method and primal heuristic, demonstrating its effectiveness in optimizing complex energy systems.

Through a case study using the example of the county Bayreuth as part of the research project 'ESM-Regio', we showcase the substantial potential of sector coupling in achieving Germany's 2045 renewable energy targets.

Defining flexibility bands to quantify load flexibility in home energy systems

Tizian Schug[1], Béla Wiegel[2], Kathrin Fischer[1]

[1]Institute for Operations Research and Information Systems, Hamburg University of Technology, Germany; [2]Institute of Electrical Power and Energy Technology, Hamburg University of Technology, Germany; tizian.schug@tuhh.de

In future energy systems, flexible resources will play a key role. Especially the increasing flexible demand in home energy systems will present challenges for the distribution grid, but it will also provide opportunities to manage problems like grid congestions. In this work, a flexibility band is defined which gives information about the load flexibility of households, which can be used by higher-level actors like grid operators or energy aggregators. The basis is given by a load trajectory of a household without external influences, which accounts for the habitants' different needs like room heating or charging of electric vehicles. A grid operator or aggregator can influence the household to change its planned load trajectory by providing an external signal, e.g. a direct intervention or a price signal. With the flexibility band, the maximum possible deviation between the reference and other load trajectories is determined which avoids compromising the habitants' comfort. Consequently, the provider of the external signal can anticipate the respective effect. While previous studies of flexibility bands rely on the exchange of state information from both, household and grid operator, here the goal is to reduce the interaction that is required by providing a corridor in which all trajectories are feasible for the home energy system. To achieve this aim, a MILP modelling concept is presented which allows to calculate the flexibility band. First results and present and future challenges are discussed as well.

Increasing Grid Stability while Charging Electric Vehicles: Incorporating Vehicle-to-Grid Aggregators into Market Equilibrium Problems

Lorenz Alexander Saathoff

Universität Hamburg, Germany; lorenz.alexander.saathoff@uni-hamburg.de

With rising sales of electric vehicles and increasing renewable energy generation, the existing electricity grid faces challenges from both the supply and demand sides. Increased renewable energy generation leads to higher volatility in production, resulting in a greater need for balancing energy. Moreover, the growing number of electric vehicles on the roads increases the demand for power, especially for fast charging at public stations.

Vehicle-to-grid (V2G) is a promising concept that intelligently manages the charging processes of electric vehicles to benefit the grid and support the integration of higher levels of volatile renewable energy. Part of the grid-connected battery capacity could be offered to the balancing energy market. To facilitate this, vehicle owners might use an aggregator service to simplify market access. This aggregator not only supplies charging stations with power sourced from the general electricity markets but also sells storage capacity and the potential to feed energy back into the grid in the balancing energy market, thus acting on different energy markets.

The aggregator aims to optimise its operation under given market conditions. This work presents an approach for integrating a vehicle-to-grid aggregator into energy market complementarity models as a market-coupling entity. In addition, a preliminary study on how market equilibria are affected under these circumstances is provided.

TC 19: Industry, Water and Urbanisation

Time: Thursday, 05/Sept/2024: 11:30am - 1:00pm · *Location:* Theresianum 1601
Session Chair: Selin Ataç

A metafrontier approach to water usage efficiency and productivity change

Sebastián Lozano[1], María del Mar Borrego-Marin[1,2]

[1]University of Seville, Spain; [2]Water, Environmental and Agricultural Resources Economics Research Group, University of Córdoba; slozano@us.es

A non-convex metafrontier approach is proposed to study the temporal evolution and the productivity change in the water usage efficiency of 91 countries for the period 2015-2020. A circular three-stage Network Data Envelopment Analysis (NDEA) model is considered. The non-radial Directional Distance Function is used to compute the system efficiency as well as that of the three stages. Three sets of NDEA models are solved: contemporaneous group, intertemporal group and intertemporal metafrontier. The corresponding Malmquist index and its decomposition into efficiency change, best practice gap change and technology gap change is computed for each country and averaged for each world region. The results found indicate that water usage inefficiency seems to be limited to a relatively small number of countries and is due to shortfalls in the gross value added and treated municipal wastewater dimensions. The inefficiency in gross value added actually shows an upward trend. The inefficiency in the water withdrawal and treated municipal wastewater dimensions have remained approximately constant during this period while the inefficiency in produced municipal wastewater have decreased slightly. As regards productivity change, most regions had a negative evolution during this period. Central Asia and Middle East-Western Asia are the exception to this trend and their productivity improvement is mostly due to an improvement in their best practice gap and, to a lesser extent, in their technology gap ratios.

Robust reverse logistics network design for polystyrene-based building insulation under uncertainty

Julia Schleier, Grit Walther

RWTH Aachen University, Germany; julia.schleier@om.rwth-aachen.de

The recycling of mixed plastic waste poses challenges for the realization of a circular economy. Specifically, for polystyrene in application within composite thermal building insulation, no recycling systems are yet in place to close material loops due to long product life cycles, material compositions that impede conventional recycling methods, and chemical recycling technologies with low TRL. To cope with increasing volumes of this polystyrene waste in the future, thorough ex-ante planning of reverse logistics networks is necessary for efficiently integrating promising chemical recycling processes, given the waste material's geographical dispersion and uncertainties regarding future return quantities per region and regulatory changes.

We aim to develop a decision support system to find optimal and robust long-term pathways and strategies for regulating and implementing sustainable recycling systems for polystyrene waste from building insulation that are economically viable. We design corresponding reverse logistics networks, accounting for uncertain polystyrene waste quantities and regulatory requirements through scenario-based robust optimization. Minimizing the expected regret in a strategic multi-period planning horizon, we integrate strategic decisions, such as technology selection of (novel) recycling options, location and capacity decisions, and tactical decisions such as material transformation and transportation.

Through our model, we mitigate the risk of developing cost-ineffective network configurations, ensure scalability to handle potential waste volumes, and address regulatory compliance. Using an application-based case study within the WSS founded research project catalaix, our study provides valuable insights for decision-makers seeking optimal strategies to manage mixed plastic waste through chemical recycling amidst uncertain developments, ultimately advancing sustainable waste management.

Optimizing Brownfield Rehabilitation: A Framework for Sustainable Urban Redevelopment

Selin Ataç, Benjamin Chevallier, Matthieu De Lapparent

Institut Interdisciplinaire du Développement de l'Entreprise (IIDE), Haute Ecole d'Ingénierie et de Gestion du Canton de Vaud (HEIG-VD), Switzerland; selin.atac@heig-vd.ch

The valorization of brownfields presents a significant challenge in urban redevelopment, as decisions in this domain involve a trade-off between environmental sustainability and financial feasibility. Our study, focusing on three sites in Switzerland, introduces a comprehensive framework integrating operations research methodologies to optimize the rehabilitation process of such sites. Within this framework, we identify key cost components related to transportation and rehabilitation expenses, which include routing, vehicle, tool, material, inventory, and recycling costs. Our framework evaluates various scenarios to find the most efficient strategy while considering (i) spatial, i.e., the location of sites and recycling facilities, (ii) technical, i.e., the quality of the material that is being recycled, and (iii) financial, i.e., budget, constraints. The scenarios are also evaluated with respect to their environmental impact: CO2 emissions, energy and water consumption are taken into account so that extra-financial factors play roles in decision-making. Evaluating options such as demolition, recycling, and upcycling for materials like cement, timber, concrete, and metal, we aim to provide actionable insights for sustainable redevelopment. The results of this research help us to propose incentives for circular economy practices in construction and promote sustainability, thus supporting a shift toward more environmentally conscious and economically viable approaches. Our interdisciplinary decision-making process addresses operational challenges and highlights the societal, economic, and environmental benefits of circular economy principles in construction.

TC 20: Sustainable Operations Management

Time: Thursday, 05/Sept/2024: 11:30am - 1:00pm · *Location:* Theresianum ZG 0670
Session Chair: Martin Glanzer

Increasing the Follow-up Rate of Patients Requiring Emergency High-Consequence Treatment

Nazli Sonmez[1], Kamalini Ramdas[2], Manavi Sindal[3]

[1]ESMT Berlin, Germany; [2]London Business School; [3]Aravind Eye Hospital; nazli.sonmez@esmt.org

A low attendance rate for urgent, high-consequence treatment is prevalent in the developing world. In poorer countries, ignorance about the illnesses people have, allied to the financial costs of attending for treatment, are two of the main reasons why they fail to show up for medical appointments. Yet, for many diseases, patients may need surgical treatment soon after diagnosis to prevent severe disability. This project aims to identify ways to increase the attendance rate of patients who need emergency high-consequence treatment. Traditionally, in care systems across the world, information about why patients must undergo a particular treatment or care plan is communicated by emphasising medical aspects of the disease, typically in scientific terms. This research, in contrast, analyses the effect of providing emotionally engaging information about how a patient's life experience can be changed by their medical condition. The study runs a two-stage, randomised controlled trial at the world's largest eye hospital, the Aravind Eye Hospital in India. This study hopes to improve the chances of poorer populations receiving the care they need and to help reduce needless blindness. Furthermore, it hopes to inspire other healthcare providers globally to adopt the proposed methods.

Sequential Clearing of Network-aware Local Energy and Flexibility Markets in Community-based Grids

Saber Talari[1], Sascha Birk[2], Wolfgang Ketter[1], Thorsten Schneiders[2]

[1]University of Cologne, Germany; [2]Cologne University of Applied Sciences, Germany; talari@wiso.uni-koeln.de

In this paper, network-aware clearing algorithms for local energy markets (LEMs) and local flexibility markets (LFM) are proposed to be sequentially run and coordinate assets and flexible resources of energy communities (ECs) in distribution networks. In the proposed LEM clearing algorithm, EC managers run a two-stage stochastic programming while considering random events by scenario generation and network constraints using linearized DistFlow. As one of outcomes, maximum available up- and down-regulations provided by ECs are estimated in LEM and communicated to LFM. In the distributed LFM clearing algorithm, an iterative auction is designed using a dual-decomposition technique (Augmented Lagrangian) which is solved by consensus alternating direction method of multipliers. The LFM algorithm efficiently dispatches the flexibility provided by ECs in operating time while considering flexibility local marginal price as pricing method. Network constraints are included in the algorithm with an AC distribution optimal power flow for dynamic network topology in which branches and buses are decomposed to solve the problem in distributed fashion. The designed LFM algorithm can respond to exogenous and endogenous signals for flexibility requests. The simulation results in a test case display effectiveness of two proposed LEM and LFM algorithms for an efficient provision of flexibility.

Sustainable supply chain network design for lithium-ion batteries using multi-objective optimization

Felix Westerkamp, Christian Thies

Hamburg University of Technology, Resilient and Sustainable Operations and Supply Chain Management Research Group; felix.westerkamp@tuhh.de

Global supply chains have been optimized in terms of economic efficiency for many years. Driven by tight regulations as well as changing expectations of customers and other stakeholders, ecological and social sustainability aspects are becoming increasingly important in supply chain network design. The mathematical formulation of the sustainable network design problem leads to a multi-objective optimization model in which several sustainability indicators need to be balanced. We leverage activity analysis for modelling the sustainability impacts of individual supply chain processes and integrating them into the optimization problem. A special feature of this approach is the consideration of different types of sustainability indicators in the model's objective function based on the decision-makers' individual preferences. The optimization of this multi-objective model with an "a posteriori" approach results in a Pareto front from which the decision-makers can select their preferred solution. We demonstrate the application of the developed model combined with a state-of-the-art solution algorithm using the supply chain for lithium-ion batteries in the field of electric mobility. In this field, the model can be used, for example, by battery manufacturers to optimize the supply chain regarding the sourcing of raw materials, or by regulators to determine the impact of regulations on the optimal supply chain network.

Sustainable Management of a System of Water Reservoirs Under Climate Uncertainty

Felipe Caro[1], Martin Glanzer[2], Kumar Rajaram[1]

[1]UCLA Anderson School of Management, Los Angeles, CA, USA; [2]University of Mannheim Business School, Germany; martin.glanzer@uni-mannheim.de

We present an optimization model for the strategic management of a system of water reservoirs, when the goal is to sustainably satisfy vital demand. Given that both standard finite horizon and discounted infinite horizon approaches seem inadequate here, we optimize the expected shortage costs over cycles. A cycle starts and ends when all reservoirs in the system are full. To account for the unpredictable effect of climate change on future water supply, we consider a robust model where nature chooses the most adversarial inflow distribution. This leads to a stochastic shortest path problem under ambiguity. We discuss structural properties of our model as well as important policy insights. To overcome the curse of dimensionality, we present a scalable heuristic together with lower and upper bounds on the (optimal/associated) expected costs, allowing to solve the policy evaluation problem. The results of a case study for the Sacramento River Basin in Northern California complement the talk.

TC 21: Railway Applications 2

Time: Thursday, 05/Sept/2024: 11:30am - 1:00pm · *Location:* Nordgebäude ZG 1070
Session Chair: Christian Liebchen

Dimensioning of track groups in rail freight stations on the basis of an optimised waiting probability

Jan Eisold, Henning Preis, Nikola Bešinović
Technische Universität Dresden, Germany; jan.eisold@tu-dresden.de

The quality-oriented and economical dimensioning of track groups (bowls) in rail freight stations is an essential task in the sustainable design of the railway network at the strategic planning level. The main task here is to determine the required number of tracks and the necessary track characteristics. In contrast to pure passenger railway stations, which today in Europe are mostly served with regular timetables and therefore experience cyclically repeating track occupancy, the performance requirements in rail freight stations are more irregular: the arrival times of the trains and the track occupancy times are often distributed rather randomly. In addition, freight train handling involves significantly more complex processes and dependencies. At present, track groups in freight stations are mainly dimensioned using analytical queueing models or simulations in which the waiting processes in front of a track group are analysed. In most cases, the waiting probability is considered as the decisive parameter. This paper describes an optimisation model that maps the track occupancy in a track group, taking into account the handling processes and complex dependencies, and minimises the number of trains waiting in front of the track group. The input data is generated using given distribution functions which anticipate expected characteristics of the later operation. Practical scenarios are used to illustrate how the approach works. In addition, a quantitative comparison is made with the methods used to date and alternative approaches for the dimensioning of track groups.

Scheduled network design for single wagon load transportation at the Swiss National Railways

Carsten Moldenhauer
SBB Cargo AG, Switzerland; carsten.moldenhauer@sbbcargo.com

The Swiss National Railways operate a single wagon load transportation system in which customers can ship demands that do not justify a unit train. Moreover, these demands are time sensitive, in particular for overnight express connections. To make this work, demands are consolidated at multiple intermediate stops, or classification yards, onto scheduled trains. The computation of the trains and their timings, and the transportation chains of the demands along the trains, is a network design problem that we model as a fixed-charge multi-commodity-flow problem on a time-expanded network.

The first main contribution of this work is the computation of small time-expansions despite the fine granularity of the intended schedules. Our methods are, in spirit, related to the dynamic discretization discovery methods by Boland and others. But in contrast, they provide an a priori sparsification of the time expansion and do not require iterative resolves to the optimization model. These small time expansions then permit an effective solution of the induced integer linear program. The second main contribution are several postprocessing mechanisms to increase the applicability of the obtained network designs for practice. The computed network designs have been used at SBB Cargo for tactical planning and commercial client offers. Experimental evaluations on some test instances from these practical examples is also provided.

An Integer Programming Model to Assign Train Drivers to Good Positions in Basic Turni

Christian Liebchen[1], Christoph Türk[2], Benedikt Vornhusen[2]
[1]Technische Hochschule Wildau, Germany; [2]COSMO Consult, Germany; liebchen@th-wildau.de

We are reporting on a project on duty rostering of a train operating company in Germany. There, in the past, rostering took place on a purely individual basis. As the goal of the project, the train drivers should work according to a set of 20 essentially fixed basic turni. These plans took into effect from January 2024 on.

In this extended abstract, we are focusing on a specific task that had to be resolved within the transition process. In particular, the fixed turni are intended to repeat periodically, most of them after 17 weeks. In particular, for that one turnus is equipped with train drivers in a balanced way, 17 employees have to be assigned to this turnus, each of them to one of the 17 different weeks of the turnus to start. To cover each day of the week, the weeks of the turnus typically differ in their number of working days.

Since the holidays of the train drivers had been already planned in advance, depending on the starting week, during the entire year, a smaller or larger number of working days of the turnus could be erased by the individual holidays. In order to preserve as many working days as necessary, a straightforward mixed-integer linear optimization problem has been designed and solved, to decide which train driver should start to work in which week of the turnus. The solution of this optimization run has been finally applied in practice.

TC 22: Last Mile Transportation 1

Time: Thursday, 05/Sept/2024: 11:30am - 1:00pm · *Location:* Nordgebäude ZG 1080
Session Chair: Caroline Friederike Ihloff

A MILP Approach for Pickup and Delivery Vehicle Routing in Last-Mile Delivery Using Modular Electric Vehicles

GOLMAN RAHMANIFAR[1], **MOSTAFA MOHAMMADI**[1,2]
[1]Sapienza University of Rome, Italy; [2]Norwegian University of Science and Technology; golman.rahmanifar@uniroma1.it

The increasing demands of last-mile delivery in a diverse range of logistical scenarios, ranging from small communities with specific needs, to dynamic urban environments where demand fluctuates significantly, highlight the necessity for innovative and efficient logistics solutions. This study introduces a novel routing strategy leveraging modular vehicle (MV) technology, which are capable of dynamic assembly and disassembly in motion. This capability facilitates platooning during transit, significantly reducing energy consumption and optimizing route efficiency. We develop a mixed-integer linear programming (MILP) model to address this 'Modular Pickup and Delivery Problem' for cargo, incorporating both in-motion transhipment and platooning to minimize delivery times and operational costs. Given that the MVs are anticipated to be predominantly electric, the model uniquely incorporates charging strategies within the operational framework to ensure continuous vehicle readiness without compromising delivery efficiency. The proposed model allows MVs to perform transhipment operations not only on arcs while platooning but also at nodes, which offers enhanced flexibility in logistics operations. The MILP formulation captures essential aspects such as vehicle platoon status, cargo en-route transhipment, variable vehicle capacity, and electric vehicle charging requirements, with constraints tailored to handle the spatial-temporal dynamics of delivery networks. The contributions extend beyond theoretical modeling to offer a scalable solution for real-world application, potentially paving the way for the improvement of last-mile delivery operations through the adoption of advanced MV technology and platooning.

Comparison of different delivery models using self-driving robots

VITTORIA CIVIERO[1], **EDOARDO FADDA**[2], **TIZIANA DELMASTRO**[3]
[1]LINKS FOUNDATION, Italy; [2]POLITECNICO DI TORINO, Italy; [3]LINKS FOUNDATION, Italy; vittoria.civiero@linksfoundation.com

Last-mile logistics has gained increasing attention in the last few years. Driven by the rise of e-commerce and the growing demand for fast deliveries, companies are exploring several strategies to optimize last-mile operations. One of the most promising options in city logistics is the Truck-and-Robot (TnR) concept that involves a truck transporting parcels and autonomous robots. This delivery system exploits a combination of drop-off points and robot depots. When a truck arrives at a drop-off point, robots are released directly from the truck to autonomously deliver goods. On the contrary, if a depot is reached, each driver unloads parcels for subsequent robot deliveries. In this paper, three delivery models have been simulated and optimized in order to determine the most effective approach. The compared methodologies are: the TnR method previously described, which enables parallelized deliveries, a standard approach, where the driver directly visits customers, and a mixed strategy where a portion of clients is served by robots and the other one by trucks. The obtained results on literature's instances and on a real use case show that the collaboration between trucks and robots (mixed strategy) is more convenient than the traditional truck service. However, an increase in robot costs strongly influences the optimal tours configuration, in favor of trucks' use. Self-driving robots are particularly suitable for simultaneous deliveries as they reduce times and costs, respecting time windows constraints. Nevertheless, traditional logistics remain faster and more efficient in scenarios where delivery parallelization is not feasible.

Customer Acceptance Strategies for Mobile Home Delivery Parcel Locker Services

Rico Kötschau, **Christian Tilk**, **Jan Fabian Ehmke**
University of Vienna, Austria; rico.koetschau@univie.ac.at

The ongoing growth of e-commerce has led to a significant increase in last-mile deliveries. New technologies are being investigated to provide these deliveries efficiently and in a customer-friendly manner. Mobile parcel lockers demonstrate an interesting extension of conventional stationary parcel lockers and attended home delivery services. During the preparation of deliveries, it is essential to consider the perspectives of both the service provider and the customer. On the one hand, service providers have many orders to fulfil and attempt to schedule each customer optimally. On the other hand, each customer has their individual availabilities and preferences. We need to consider firstly, whether the customer prefers to be delivered at home or from a parcel locker; secondly, within what time period; and thirdly, how far the customer is willing to travel for pickup. To ensure optimal routing, these requirements must be aligned with the current and incoming order situation. Consequently, providers offer customers a selection of possible delivery slots from which they then choose the one that suits them best. It is important which slots are offered to which customer, as the selection has a strong impact on if and how subsequent customers can be served. We therefore present a customer acceptance procedure in which customers can be served with mobile parcel locker or attended home delivery services and evaluate preliminary offering strategies in terms of performance (accepted customers) and service quality (travel distance and service provision period).

Integrating Driver Preferences in Urban Delivery

Caroline Ihloff, **Marlin Ulmer**
Otto-von-Guericke Universität, Germany; caroline.ihloff@ovgu.de

In times of skilled labor shortages, it becomes essential for delivery companies to stand out from their competitors. Creating a supportive work environment where employees feel valued is key to achieve this goal. For example, recent studies have shown that delivery drivers have different preferences when it comes to parking and how far they are willing to walk. These preferences can vary for each driver based on factors like age or experience. For instance, experienced drivers are skilled to approach difficult parking spots but might not want to walk long distances. The challenges of parking and walking also vary depending on the area of the city, e.g., in commercial, downtown, or rural areas.

Consequently, delivery companies may want to integrate individual driver preferences in their operational planning of delivery routes. To show the impact of such integration, we present a multi-objective vehicle routing problem. Using Berlin as a case study, we examine the balance between driver convenience and travel cost. Our findings demonstrate that integrating driver preferences into planning models can be achieved at relatively low cost.

TC 23: Drone Transportation

Time: Thursday, 05/Sept/2024: 11:30am - 1:00pm · *Location:* Nordgebäude ZG 1090
Session Chair: Manuel Ostermeier

A MILP formulations and a branch-and-cut approach for several truck-and-drone logistics problem

Maurizio Boccia[1], Adriano Masone[1], Claudio Sterle[1,2], Andrea Mancuso[1], Danilo Amitrano[1]

[1]University Federico II of Naples, Naples, Italy; [2]IASI – Institute for System Analysis and Computer Science, Rome, Italy; claudio.sterle@unina.it

Nowadays, truck-and-drone problems represent one of the most studied classes of vehicle routing problems. The Flying Sidekick Traveling Salesman Problem (FS-TSP) is the first optimization problem defined in this class. Since its definition, several variants have been proposed differing for the side constraints related to the operating conditions and for the structure of the hybrid truck-and-drone delivery system. However, regardless the specific problem under investigation, determining the optimal solution of most of these routing problems is a very challenging task, due to the vehicle synchronization issue and drone hovering.

On this basis, this work provides a new arc-based integer linear programming formulation for the FS-TSP. The proposed formulation is quite general and can be easily extended to deal with two interesting variants of the FS-TSP, namely: the Traveling Salesman Problem with Drone and Lockers (TSP-DL), where customers are served either by truck or a drone directly at their houses or use self-pickup facility (i.e., lockers); the Truck-Drone Team Logistics Problem (TDTLP), where a drone can serve multiple customers during in each flight.

The solution of the proposed formulation and its variants required the development of a branch-and-cut solution approach based on new families of valid inequalities and variable fixing strategies.

We tested the proposed approach on different sets of benchmark instances. The experimentation shows that the proposed method is competitive or outperforms the state-of-the-art approaches, providing either the optimal solution or improved bounds for several instances unsolved before.

Multi-Region UAV Operation Planning under Visual Line of Sight Restrictions

Manuel Ostermeier, Lukas Bante

University of Augsburg, Germany; manuel.ostermeier@uni-a.de

Robotic applications in production and logistics generally require collaboration and coordination between robots and humans. Smooth human-robot interaction is essential to ensure efficient operations and requires integrated planning of both actors. This contribution investigates robot and human collaboration planning for unmanned aerial vehicle (UAV) applications requiring the overflight of multiple, spatially distributed regions, where each region contains a dense set of target locations. As the human operator must maintain a continuous visual line of sight (VLOS) to the UAV in flight, its freedom of movement is restricted. The operator must also ferry the UAV between a separate set of potential takeoff and landing locations. Such problems can be found, among others, in last-mile logistics, survey missions, or agricultural settings for the deployment of biological pest control. Considering VLOS in these planning problems is paramount to allow the implementation of solution approaches under the current strict legal and operational restrictions currently in force in a wide range of jurisdictions, including the European Union.

We present a mathematical model formulation of the problem and develop a tailored solution approach to generate feasible, high-quality solutions in reasonable computation times. Algorithmic performance and solution quality are evaluated for several scenarios derived from real-world data.

TD 01: GOR Young Researchers Award

Time: Thursday, 05/Sept/2024: 2:00pm - 3:30pm · *Location:* Audimax
Session Chair: Stefan Ruzika

An integrated bi-objective optimization model accounting for the social acceptance of renewable fuel production networks

Tristan Becker
TU Dresden, Germany; msci@tu-dresden.de

Renewable liquid fuels produced from biomass, hydrogen, and carbon dioxide play an important role in reaching climate neutrality in the transportation sector. For large-scale deployment, production facilities and corresponding logistics have to be established. However, the implementation of such a large-scale renewable fuel production network requires acceptance by citizens. To gain insights into the structure of efficient and socially accepted renewable fuel production networks, we propose a bi-objective mixed-integer programming model. In addition to an economic objective function, we consider social acceptance as a second objective

function. We use results from a conjoint analysis study on the acceptance and preference of renewable fuel production networks, considering the regional topography, facility size, production pathway, and raw material transportation to model social acceptance. We find significant trade-offs between the economic and social acceptance objective. The most favorable solution from a social acceptance perspective is almost twice as expensive as the most efficient economical solution. However, it is possible to strongly increase acceptance at a moderate expense by carefully selecting sites with preferred regional topography.

Request acceptance with overbooking in dynamic and collaborative vehicle routing

Yannick Scherr
Universität Wien, Austria; yannick.scherr@univie.ac.at

We consider the problem setting of a less-than-truckload carrier serving stochastic customer requests. Each request must be answered dynamically by accepting or rejecting it immediately. On the next day, accepted requests are served in routes using a set of vehicles with limited load capacity and route duration. After the request acceptance phase and before the fulfillment, multiple carriers participate in a combinatorial auction to exchange requests. An auctioneer allocates the bundles of requests to carriers according to their bids in a cost-minimizing way and distributes the auction profits. This type of horizontal collaboration provides cost savings and contributes to reducing negative impacts of transportation. We describe the carrier's optimization problem of maximizing profit as a Markov decision process that comprises the sequential decisions in all phases, i.e., request acceptance, request selection for the auction, bidding, and routing. For solving a version of the vehicle routing problem with pickups and deliveries, heuristic approaches are proposed that achieve efficient and balanced routes. We design overbooking policies for strategically accepting more requests bearing in mind the options provided by the auction. Computational results show that – by trading requests in an auction –

carriers can accept more requests than they could serve on their own. The carriers' request acceptance decisions impact their individual profits and the overall collaboration savings. The largest benefits can be achieved with an overbooking policy that prescribes which requests should be accepted by all carriers, based on the locations of both the request and the carriers' depots.

Matching supply and demand for free-floating car sharing: On the value of optimization

Felix Weidinger
Technische Universität Darmstadt, Germany; felix.weidinger@tu-darmstadt.de

After a promising ramp up, free-floating car sharing is about to establish itself as a mainstream mobility option in many urban areas. This form of short-term car rental allows users to begin trips wherever they are offered an available car and end them at their most convenient position. Current implementations are not based on optimization; each user decides locally whether to place a short-term reservation among available cars. This paper evaluates the potential gains for a car sharing provider if, instead, a sophisticated optimization algorithm is applied to match demand and supply centrally. For this purpose, we formulate the car-request assignment problem, provide a heuristic solution approach, and show how to apply it in different booking processes. Specifically, we compare the status quo with different optimization-based matching approaches, where either the booking with all its details is instantaneously confirmed to the customer or only a service promise is accredited, but the final specification of the car is postponed. Furthermore, we differentiate whether incoming customer requests are collected for a short batching interval and then jointly optimized, or if each customer receives immediate feedback. In a computational study, based on generated and real-world data, these five different booking policies are benchmarked in a dynamic environment where new requests appear over time. The computational tests also evaluate the impact of no-shows, late car returns, and the application of relocators. The results reveal that, once customers are willing to accept an altered booking process, an optimization-based matching mechanism promises considerable improvement of services.

Optimizing combined tours: The truck and cargo bike case

Philine Schiewe
Aalto University, Finland; philine.schiewe@aalto.fi

In this paper, we introduce a last-mile delivery concept that is well suited for urban areas. By jointly optimizing the tour of a truck and a cargo bike, we ensure that each vehicle is used optimally. Here, we assume that the bike is restocked by meeting up with the truck so that no dedicated mini-hubs have to be constructed. We model different objective functions and analyze the different variants in comparison to the traveling salesperson problem as well as the capacitated vehicle routing problem.

In an experimental evaluation, we compare MIP formulations for different problem variants and assess several heuristic approaches to solve large-scale instances. These results show that we can outperform the truck-only delivery in terms of completion time while reducing the distance driven by the truck.

TD 02: Machine Learning for Supply Chain Optimization

Time: Thursday, 05/Sept/2024: 2:00pm - 3:30pm · *Location:* Theresianum 0602
Session Chair: Krunal Arun Padwekar

Design End-to-End Supply Chain Optimization by Embedding Business Knowledge and Advanced Analytics

Matej Lebl[1], Li Gan[2]
[1]MSD, Czech Republic; [2]MSD, Switzerland; matej.lebl@merck.com

Modelling and Optimization of end-to-end supply chain network which reflects daily planning and execution is challenging, especially when the network is complex with multi-echelon and the number of products within the network is large. In this paper, we propose a new method of modelling complex end-to-end supply chain network with both planning and execution activities, accelerating the simulation of network model with large number of products by decomposition, embedding business rules, and optimizing large amount of planning parameters using tailor designed optimization algorithm with embedded knowledge from business, advanced analytics and machine learning. The results demonstrate that the simulation and optimization process can be greatly speed up and the quality of proposed planning parameters can be well improved.

Towards a Sustainable Agri-Food Supply Chain by integrating Farm Management Decisions: Application of Hierarchical Reinforcement Learning

Krunal Padwekar, Kanchan Awasthi, Subhas Chandra Misra
Indian Institute of Technology Kanpur, India; Kp2018@outlook.in

Farm Management Decisions, such as crop selection or, irrigation and fertilisation, are dependent on farmers' discretion and may cause significant damage to the environment. This can be due to overuse of water and nitrogen-based fertilisers. Farmers may be forced to grow certain crops as they might be limited by available market (or supply chain) or existing economic policies. Economic policies, which are unilaterally prescriptive, may not include proper feedback to assess harm caused by selection of certain types of crops and their requirements. This may cause distress to farmers, loss to governments or supply chain entities, and damage to the environment. Hence, a comprehensive approach is needed for sustainability.

The proposed model consists of three levels:

1. Farms: Optimising the amount of ground water loss, nitrogen leaching, growth of crop main product and by-products. For this, we use gym-DSSAT that is a well-considered crop simulation model in a Reinforcement Learning environment.

2. Post-Harvest Processing: Optimising cost of processing, storing, or selling the processed products to distributors or end-consumers.

3. Distribution: Weekly capacity allocation and utilisation for product distribution.

Integration of above in a single model leads to high dimensionality. Therefore, Multi-Agent Hierarchical Reinforcement Learning has multiple advantages: (1) This is a modular approach for each level hence behaviours might be turned into specific tasks. (2) Since the high-level agent may ignore implementation specifics, exploration is improved. (3) Sample efficiency is improved. (4) This isolation of decisions leads to overall robustness. (5) Each policy can be transferred to new environments.

Anomaly Detection and Operational Efficiency in Supply Chains

Bowei Gao[1], Maximilian Moll[2], Stefan Pickl[2]
[1]Leiden University; [2]University of the Bundeswehr Munich; b.gao@umail.leidenuniv.nl

In this contribution, we address the challenge of anomaly detection within the logistics sector, especially supply chains, conceptualizing it as a task of categorizing logistics records into anomalous and normal categories. This classification is approached through both supervised and unsupervised learning methods. We detail the rationale behind selecting these methodologies and present a comparative analysis of their performance and efficiency, delving into the underlying reasons for their effectiveness.

The main findings indicate that for simpler logistic datasets, either supervised or unsupervised learning techniques can be effectively applied. However, for more complex datasets that necessitate guided learning, supervised methods become essential.

We introduce a novel unsupervised anomaly detection approach tailored to logistics, which leverages the strengths of autoencoders and clustering techniques to enhance detection speed and accuracy.

Additionally, leveraging the insights from feature importance metrics derived from supervised learning models, we further investigate the factors significantly impacting the timeliness of logistics operations. This exploration not only advances our understanding of anomaly detection in logistics but also contributes practical insights for enhancing operational efficiency in the domain.

TD 03: Data-Driven Optimization

Time: Thursday, 05/Sept/2024: 2:00pm - 3:30pm · *Location:* Theresianum 0606
Session Chair: Jan Fabian Ehmke

Operational Optimization of FttH Networks: A Data-Analytic Approach Using Clustering and Contract Theory

Mohamed Saâd EL HARRAB[1,2], Michel NAKHLA[1]

[1]Center for Management Science (CGS), i³ UMR 9217 CNRS, Mines Paris, PSL University; [2]École des Ponts ParisTech; mohamed-saad.el_harrab@minesparis.psl.eu

The deployment of Fibre to the Home (FttH) networks represents a critical advancement in the telecommunications sector, enabling the provision of high-speed internet access to fixed-line customers. Although the implementation of FttH has been successful in urban areas, the expansion into less dense regions remains a financial challenge.

In alignment with the "France Très Haut Débit" initiative, our study introduces a novel approach utilizing HDBSCAN clustering to optimize FttH deployment strategies in zones with uneven population densities. This methodology leverages geospatial data for the precise design and cost estimation of network infrastructures, facilitating effective and efficient resource allocation.

Additionally, this work examines the dynamics of public-private partnerships (PPPs) under incomplete contract theory. We analyze regulatory adjustments and strategic participation needed to sustain private investment in public services without complete financial guarantees. Through this dual approach, our research contributes to the broader discourse on telecommunications infrastructure development, offering scalable solutions and policy recommendations for the deployment of FttH networks in diverse demographic settings.

A top-weighted algorithm for comparing incomplete and non-conjoint rankings based on their correlation

Christoph Strauss[1], Lin Himmelmann[1], Daniel Politze[1], Remo Fankhauser[1], Andreas Ruckstuhl[2]

[1]OST - Ostschweizer Fachhochschule, Switzerland; [2]ZHAW - Zürcher Hochschule für Angewandte Wissenschaften, Switzerland; christoph.strauss@ost.ch

Ranked lists are often found in applications, such as comparing the results of a query sent to two search engines. In our use case, participants ranked a list of ideas by assigning a value (the “benefit”) to each idea – the higher the benefit, the better the idea. Now, questions arise such as the similarity of rankings by different users or different groups of users, which naturally leads to the need for a measure of ranking similarity. We start with a brief discussion of Kendall's tau, to show its limitations with respect to situations where (i) differences in the top ranks are considered more important than differences in the tail (the top-weighted aspect), (ii) it is not feasible or useful to compare the full ranking (the completeness aspect), (iii) two rankings may have different entries for reasons related to the evaluation process (the nonconjointness aspect), and (iv) the correlations of the benefits should be utilized to account for the benefits’ statistical uncertainty (the correlations aspect). We then present a new algorithm that combines Carterette’s statistical approach with Webber et al.’s rank-biased overlap (RBO) method to satisfy all requirements (i) – (iv). Finally, we present results from simulation studies that demonstrate the practicability of the new algorithm.

Machine Learning Models to Optimize Energy Consumption of Electrical Locomotives

Fatih Kocatürk[1], Daniele Giannandrea[2], Gislind Stefan[1], Jan Fabian Ehmke[1]

[1]Department of Business Decisions and Analytics, University of Vienna, Austria; [2]Dwh GmbH, Austria; fatihkocaturk438@gmail.com

Transportation is one of the largest contributors to carbon emissions. In railway transportation, optimizing train schedules, circulation plans, and locomotive assignments to minimize energy consumption offers great potential for energy savings. In the railway literature, the most preferred approach to modeling energy or fuel consumption is deterministic modeling, particularly using the Davis model, which calculates the resistance force required to keep the train moving at a constant speed. However, these models were developed many years ago through experimental work on old types of diesel locomotives and require parameter adjustment to be used today. In recent years, electric locomotives are generally used in rail transportation, and the energy consumption of locomotives can be recorded at certain time intervals by using some sensors. In this study, to predict the energy consumption of electrical locomotives using data-driven methods, first train time schedules, locomotive energy consumption data (by the Austrian Federal Railways, ¨ OBB), and some infrastructure information are merged. Then, the most significant parameters affecting energy consumption are found by performing feature analysis on the acquired dataset. The effective parameters obtained are utilized as input for machine learning models, including XGBoost (eXtreme Gradient Boosting) and Random Forest, which are trained to predict the energy consumption of locomotives. These models, which have demonstrated success in regression predictive modeling applications, predict energy consumption with an R2 value of 0.88. Finally, the trained models are integrated into a meta-heuristic algorithm and agent-based simulation model developed for the locomotive assignment problem.

TD 04: Location and Supply Chain Management under Uncertainty

Time: Thursday, 05/Sept/2024: 2:00pm - 3:30pm · *Location:* Wienandsbau 2999
Session Chair: Babooshka Shavazipour

A robust multi-objective optimization model for designing a resilient and responsive supply chain

Malihe Ebrahimi[1], Adel Aazami[2]

[1]Kosar University of Bojnord, Iran; [2]Vienna University of Economics and Business, Austria; adel.aazami@wu.ac.at

Disruptions, such as unexpected incidents, pose irreparable costs to the supply chain (SC) network. In this paper, to protect against these disruptions, a robust three-objective optimization model is developed for a resilient and responsive SC under uncertainty. Objectives are costs, quality of the raw and final products, and response time in designing a four-level resilient and responsive SC, including suppliers, manufacturers, distributors, and customers. Resilient strategies are employed to manage the possible disruption for suppliers and manufacturers, including repair and improvement, strengthening, and backup sourcing. In the first place, if the disruption occurs to the suppliers, backup suppliers should be replaced. However, this replacement requires extra costs, and the backup suppliers may not have the essential quality. Therefore, in the developed model, the best supplier is chosen based on its raw material quality, resilience ability, and cost. Secondly, if the disruption happens to the manufacturers, in addition to the backup manufacturer option, another resilience strategy can be employed, named repair and improvement. In this strategy, a penalty cost should be paid proportionate to the time spent repairing, and the current manufacturer should continue producing the ordered product. Additionally, in this study, the operational uncertainty of some parameters is dealt with by utilizing robust optimization. Finally, the Benders decomposition algorithm is proposed to solve the NP-hard model in large sizes.

Optimizing Location Choices for Mobile Stores: Policies for Location Selection

Florian Cramer, Christian Fikar

University of Bayreuth, Germany; florian.cramer@uni-bayreuth.de

In recent years, customers have been rediscovering local markets while firms seek ways to shorten supply chains and strengthen local industries. With increasing interest in local and regional produce, mobile stores, known as pedlars, are gaining attention as a channel for supporting local entrepreneurs. This study addresses the challenge of selecting optimal locations for mobile stores when customer demand, availability, and spending at locations are uncertain. We evaluate various location selection policies using agent-based simulation and compare them to a reinforcement learning approach. To this end, we model and develop policies based on practitioner interviews. Using agent-based simulation allows us to model and simulate seemingly random differences between locations as described by practitioners, thus providing decision support.

Multi-scenario multiobjective robust optimization for forest harvest scheduling under uncertainty

Babooshka Shavazipour[1], Lovisa Engberg Sundström[2]

[1]University of Jyvaskyla, Finland; [2]Skogforsk, Uppsala, Sweden; babooshka.b.shavazipour@jyu.fi

In this study, we have designed a multiobjective decision support tool prototype for robust forest harvest scheduling in multiple periods. Indeed, we formulated and solved a novel multi-scenario multiobjective mixed-integer optimization problem, with 108 objective functions, providing support for forest planners to study the existing trade-offs between demand satisfactions for multiple assortments in different planning periods. Besides, an interactive robust analysis to study the outcomes variations caused by uncertainty and find a robust schedule in tactical forest planning problems has been proposed. We validated the useability of the proposed decision-support prototype with a Swedish case study with a harvest planning horizon of twelve months.

TD 06: Quantum Computing

Time: Thursday, 05/Sept/2024: 2:00pm - 3:30pm · *Location:* Wirtschaftswissenschaften Z534
Session Chair: Thorsten Koch

Quantum annealing and the stable set problem

Dunja Pucher[1], Janez Povh[2,3], Aljaž Krpan[2,3]
[1]University of Klagenfurt, Austria; [2]Rudolfovo, Science and Technology Centre Novo mesto, Slovenia; [3]University of Ljubljana, Slovenia; dunja.pucher@aau.at

Given an undirected graph, the stable set problem asks to determine the cardinality of the largest subset of pairwise non-adjacent vertices. This value is called the stability number of the graph, and its computation is an NP-hard problem. In our research, we focus on solving the stable set problem using the D-wave quantum annealer. By formulating the problem as a quadratic unconstrained binary optimization problem with the penalty method, we show that the optimal value of this formulation is equal to the stability number of the graph for certain penalty parameter values. However, the D-Wave quantum annealer is not an exact solver, so the solutions may be far from the optimum and may not even represent stable sets. To address this, we introduce a post-processing procedure that identifies samples that could lead to improved solutions and extracts stable sets from them. In addition, we propose a so-called simple CH-partitioning method to handle larger instances that cannot be embedded on D-Wave's quantum processing unit. Finally, we investigate how different penalty parameter values affect the solutions' quality. Extensive computational results show that the post-processing procedure significantly improves the solution quality, while the simple CH-partitioning method successfully extends our approach to medium-size instances.

Enhancing Qubo Solver Efficiency through Refined Computational Techniques

Daniel Rehfeldt, Thorsten Koch, Yuji Shinano, Shanwen Pu
Zuse Institute Berlin, Germany; pu@zib.de

The Quadratic Unconstrained Binary Optimization (QUBO) problem plays a crucial role in combinatorial optimization and has garnered increased interest with the rise of quantum computing. This talk presents improvements in the state-of-the-art QUBO solver, Qubowl, through refined computational techniques. Our primary focus is on addressing inefficiencies in components of parallel frameworks, notably information loss during node transfers. In our research, we identify several potential drawbacks in the implementation, which we address by carefully evaluating which information should be transferred. This evaluation helps maintain a better trade-off between communication cost and information loss. These enhancements are integrated into the Qubowl solver, which also features a parallel implementation to elevate performance. Comparative empirical evaluations reveal that our enhanced solver achieves improved speed over existing problems, especially in processing sparse QUBO instances.

Intractable Decathlon: Benchmarking quantum and other novel hardware approaches on challenging discrete optimization problems

Thorsten Koch
Zuse Institute Berlin / TU Berlin, Germany; koch@zib.de

New hardware approaches are emerging, with quantum computers at the forefront, along with other systems such as data-flow machines, mem-computing, and bifurcation chips. All have in common their claim to "solve" challenging, i.e., NP-hard, combinatorial optimization problems more effectively than traditional methods.

NP-hard problems are referred to as "intractable", and, therefore, considered challenging to solve. However, this characterizes the theoretical worst-case complexity for the entire class of problems. The assertion that finding a solution is exceedingly difficult pertains to the decision problem. In contrast, identifying some feasible solution to the optimization version of the problem is often straightforward. For instance, any permutation of cities constitutes a valid tour for the Traveling Salesperson Problem (TSP). The challenge lies in discovering the optimal tour and proving its optimality.

The new approaches primarily can provide "good" solutions but fall short of proving optimality. The theoretical debate extends to whether and to what extent these problems can be approximated in polynomial time. However, the assurance an approximation algorithm offers is merely a lower bound on the solution's quality. Numerous questions remain unanswered, and ultimately, the only method to evaluate the practical performance of heuristic algorithms is to benchmark them against relevant instances. We selected model-independent instances from a diverse set of problem classes where classic exact and heuristic methods are known to have a difficult time. We will present our insights and performance results from classical, quantum, and other new systems.

TD 08: Bilevel Optimization

Time: Thursday, 05/Sept/2024: 2:00pm - 3:30pm · *Location:* Wirtschaftswissenschaften Z538
Session Chair: Henri Lefebvre

A New Algorithm for Solving Bilevel Problems with Bilinear Terms of Upper and Lower Level Variables

Sina Hajikazemi, Florian Steinke

TU Darmstadt, Germany; sina.hajikazemi@eins.tu-darmstadt.de

Bilevel optimization problems where the lower level includes bilinear terms involving both upper and lower level variables pose significant challenges, since replacing the lower level problem with its KKT conditions does not lead to the common MILP structure. This study introduces a novel algorithm designed to effectively address such bilevel problems. The proposed method is an extension of the recently proposed Penalty Alternating Direction Method (PADM). A straight-forward application of PADM to the considered setting would lead to non-convex QPs in each update step of the upper level variables together with the primal variables of the lower level problem. Direct linearizing of this step does not lead to useful updates since the interaction between the two variables is not considered accurately enough. Instead, we propose to add an outer loop of linearization to the PADM process. To validate the efficacy of the new algorithm, we conduct experimental tests using examples from the robust design of multi-modal energy systems. With the proposed algorithm we can find feasible solutions that are practically plausible, even for problems with up to several hundred thousand variables.

Solving Bilevel QPs with Nonconvexities in the Lower Level

Immanuel Bomze[1], Andreas Johannes Florian Horländer[2], Martin Schmidt[2]

[1]University of Vienna, Austria; [2]Trier University, Germany; horlaender@uni-trier.de

In this presentation we consider bilevel problems with a convex-quadratic mixed-integer upper-level and a nonconvex, quadratic, and continuous lower-level problem. We show that this class is in the second level of the polynomial hierarchy and present a lower- and upper-bounding scheme that provably solves these problems to global optimality in finite time. Therefore, we make use of the Karush-Kuhn-Tucker conditions of the lower-level problem to obtain dual bounds. Finally, we illustrate the applicability of our novel method using some preliminary numerical results.

A First-Relax-then-Reformulate Approach for Bilevel Problems with Nonconvex Mixed-Integer Nonlinear Lower Levels

Henri Lefebvre, Martin Schmidt

University Trier, Germany; lefebvre@uni-trier.de

In this talk, we consider bilevel optimization problems in which the follower solves a nonconvex mixed-integer nonlinear problem and all leader decisions are binary. For this challenging class of problems, we introduce a first-relax-then-reformulate approach to compute feasible points of good quality. Our algorithm is based on approximating the value function of the follower's problem by using a tailored penalty approach. In the most general setting, we show that this approximation can be made arbitrarily close to the original value function. We further show that, for mixed-integer linear problems, our approximation is exact, i.e., it coincides with the original value function. For both cases, we then derive a new column-and-constraint generation algorithm, which makes use of the novel approximation to guide the search towards feasible or even optimal points. Finally, we report computational results on instances taken from the literature that show the applicability of the approach.

TD 09: Revenue Management for Deliveries and Routing Problems

Time: Thursday, 05/Sept/2024: 2:00pm - 3:30pm · *Location:* Wirtschaftswissenschaften Z532
Session Chair: Rouven Schur

Dynamic Pricing for Crowdsourced Delivery Platforms

Georgina Nouli[1], Axel Parmentier[2], Maximilian Schiffer[1,3]
[1]School of Management, Technical University of Munich; [2]CERMICS, École des Ponts, Marne-la-Vallée, France; [3]Munich Data Science Institute, Technical University of Munich; georgina.nouli@tum.de

Crowdsourced delivery offers a compelling alternative to traditional delivery services, with benefits including reduced costs, faster delivery times, greater adaptability, and contributions to sustainable urban logistics. However, the compensation that a crowdsourced platform offers to gig workers significantly affects their acceptance probability for each delivery request. Therefore, the success of a platform that utilizes crowdsourced delivery relies on finding a pricing policy that strikes a balance between creating attractive offers for gig workers and ensuring profitability. In this work, we study a dynamic pricing problem from the perspective of a central operator responsible for determining request-specific compensation for gig workers. We examine a discrete-time framework where delivery requests and gig workers arrive stochastically. Each gig worker is willing to serve one request at a time for a fee. The operator aims to find a pricing policy that maximizes the total expected reward from servicing customer requests within the time horizon. In this context, we employ the Multinomial Logit model to represent the acceptance probabilities of drivers. As a result, we can derive an exact solution that utilizes the post-decision states, i.e., the intermediate states immediately after a driver has decided on which delivery request to accept but before any additional stochastic information is revealed to the system. Subsequently, we integrate this solution into an approximate dynamic programming algorithm. We compare our algorithm against benchmark algorithms, including formula-based policies and the upper bound provided by the full information linear programming solution, and show that it is superior to existing algorithms.

From approximation errors to optimality gap - exploiting structural knowledge of opportunity cost in integrated demand management and vehicle routing problems

David Fleckenstein[1], Robert Klein[1], Vienna Klein[1], Claudius Steinhardt[2]
[1]University of Augsburg, Germany; [2]University of the Bundeswehr Munich, Germany; vienna.klein@uni-a.de

The widespread adoption of digital distribution channels both enables and forces more and more logistical service providers to manage booking processes actively to maintain competitiveness. As a result, their operational planning is no longer limited to solving vehicle routing problems. Instead, demand management and subsequent vehicle routing problems are integrated to steer the booking process with the aim of optimizing the downstream fulfillment operations. The resulting integrated demand management and vehicle routing problems (i-DMVRPs) can be modeled as Markov decision process and, theoretically, solved via the well-known Bellman equation. Unfortunately, the Bellman equation is intractable for industry-sized instances. Thus, in the literature, i-DMVRPs are often addressed via opportunity cost approximation approaches. However, the overall performance of the respective approaches largely varies between different instance structures. Furthermore, to the best of our knowledge, there is neither a structured procedure to analyze the corresponding root causes nor general guidelines on when to apply which class of approximation approach. In this work, we address this gap by proposing a structured method to analyze, explain and compare the performance impact of different opportunity cost approximation-based solution approaches for i-DMVRPs. Further, we identify common patterns in approximation errors and derive general guidelines for an informed algorithm development process.

Optimizing Last-Mile Delivery: A Dynamic Compensation Framework for Engaging Occasional Drivers

Rouven Schur[1], Matthias Soppert[2], Kai Winheller[1]
[1]University Duisburg-Essen, Germany; [2]University of the Bundeswehr Munich, Germany; rouven.schur@uni-due.de

Amid the rapid growth of online retail, last-mile delivery faces significant challenges, including the cost-effective delivery of goods to all customers. Accordingly, the development and improvement of innovative approaches thrive in current research. Our work contributes to this stream by applying dynamic pricing techniques to effectively model the possible involvement of the crowd in fulfilling delivery tasks. The use of occasional drivers (ODs) as a viable, cost-effective alternative to traditional dedicated drivers (DDs) prompts the necessity to focus on the inherent challenge posed by the uncertainty of ODs' arrival times and willingness to perform deliveries.

We propose a dynamic programming framework that determines specific compensation for each delivery task to engage the crowd. This model, resembling a reversed form of dynamic pricing, incorporates ODs' decision-making by considering their unknown destinations and potential detours when accepting a delivery task. Our approach addresses the dynamic and stochastic nature of OD availability and decision-making.

We analytically solve a one-dimensional optimization problem, where all delivery locations are on a straight line, and identify key properties. These insights are then extended to the more complex two-dimensional case. We present our solution method for developing an effective compensation scheme, demonstrating its potential to improve last-mile delivery efficiency.

TD 10: Workforce Scheduling

Time: Thursday, 05/Sept/2024: 2:00pm - 3:30pm · *Location:* Wirtschaftswissenschaften 0514
Session Chair: Gerriet Fuchs

Behavior-Aware Scheduling of Healthcare Workers

Lorenz Wagner[1], Sebastian Schiffels[1], Jens Brunner[2]

[1]Universität Augsburg, Germany; [2]Technical University of Denmark, Denmark; lorenz.wagner@uni-a.de

An efficient use of medical staff, i.e., efficient scheduling, is vital for hospitals due to increasing economic pressure. However, the shortage of skilled workers in hospitals is a serious problem that (partly) results from unattractive working hours. Thus, creating attractive working conditions is crucial to counteract this shortage. The current state of the literature addressing quantitative healthcare scheduling approaches largely neglects behavioral findings regarding worker behavior while behavioral studies leave open how the behavioral insights gained are to be implemented in workforce schedules. This paper aims to close this gap by investigating whether incorporating behavioral insights into quantitative scheduling can provide benefits to both medical staff and hospital management. Specifically, the trade-off between schedule consistency (preferred by workers) and worker flexibility (favored by planners) is quantified. A MILP model is developed that complements common hospital regulations with constraints designed to model performance degradation and recovery due to scheduling inconsistencies. The model captures how inconsistent shift patterns impair worker performance over time, while consistent schedules allow adaptation and performance recovery. Due to the computational complexity, we decompose the compact model via the Dantzig-Wolfe decomposition and solve it using a column generation approach. Our findings offer insights into how accommodating human behavioral factors within optimization models can enhance both employee satisfaction and operational performance in healthcare staff scheduling. Consequently, this work provides a foundation for rethinking workforce scheduling practices to create schedules that are not only feasible but also desirable from both the employee and management perspectives.

A Decision Support System for Nurse Rostering using Stints and Integer Programming

Harold Tiemessen[1], Samuel Kolb[1], Reinhard Buergy[2]

[1]Eastern Switzerland University of Applied Sciences, St.Gallen, Switzerland; [2]Polypoint AG, Gümligen, Switzerland; harold.tiemessen@ost.ch

Offering a healthy work-life-balance to its employees is a big challenge for healthcare institutions. This is particular true, for employees that work in shifts, like nurses. Negative effects of shift work can be reduced by giving employees better opportunities to shape their working schedule. Currently, there is a lack of tools for automated schedulers that consider the interests of all stakeholders.

We present a Decision Support Systems (DSS) that allows nurses to enter their needs and preferences in an app and contains advanced models and algorithms to create excellent and fair rosters. Planners usually only need to make small adjustments (usually due to undocumented and/or soft information) before generated rosters are finalized and released. We developed an Integer Programming model that uses stints (predefined sequences of shifts and rest days) as decision variables. They are generated in a preprocessing step via simple construction heuristics and/or employee preferences. Stints constitute a useful interface between employee and mathematical model and allow easy formulation of complex working time regulations, demands per skill patterns, and employees needs and preferences.

We have tested our DSS for several months in real-life settings in various departements of hospitals and nursing homes in Switzerland and Liechtenstein. Using our DSS, the shift planners find good schedules in short time. The participative approach led to great acceptance among employees, planners, and healthcare institutions. We present interesting numerical results and valuable best practices based on our experiences so far.

Fairness in personnel scheduling using preferences

Gerriet Fuchs, Katja Schimmelpfeng

Universität Hohenheim, Germany; gerriet.fuchs@uni-hohenheim.de

Personnel, particularly in the healthcare sector, represents an exceptionally rare and valuable asset. Consequently, maintaining employee satisfaction is paramount. One strategy healthcare institutions are adopting involves incorporating employees' preferences into the planning process. Our study aims to ascertain whether individual employees could potentially skew the final plans in their favor by misrepresenting their preferences. Furthermore, we seek to identify the variables on which this possibility depends. To this end, we will conduct a focused, small-scale study specifically addressing this issue. During our presentation, we will both outline the problem setting and delve into the variables, examining how they influence the scenario. Our primary interest lies in exploring the strategies employed by the employee, the nature of the planning process, and the characteristics of the problem instances, including their size and type.

TD 11: Learning in Economics

Time: Thursday, 05/Sept/2024: 2:00pm - 3:30pm · *Location:* Theresianum 2609
Session Chair: Julius Durmann

Structural Estimation via Equilibrium Learning

Markus Ewert, Martin Bichler
Technical University of Munich, Germany; markus.ewert@cit.tum.de

In economic theory it is typically assumed that agents choose their actions based on an equilibrium strategy. Determining this equilibrium behavior is crucial, but understanding the inverse problem, where observed actions are used to infer the underlying valuations leading to such behavior, is equally significant. The field of structural estimation employs statistical techniques to explore this issue. Initial methods were limited to simple settings due to the computational hardness of the equilibrium problem. Further developments in this field have bypassed the need for an analytical equilibrium by representing the latent parameters as a function of the observed actions. Although this task is not as hard as deriving the equilibrium strategy analytically, it is still challenging. Thus, these approaches are limited to rather simple auction settings. In this study, we draw on recent advances in equilibrium learning to address these challenges. Therefore, it is only necessary to specify the underlying game and not perform complex transformations. We introduce an estimation framework that utilizes Normalizing Flow models to represent the latent parameters, such as prior distributions in auction games. This framework iteratively optimizes these models by comparing the induced equilibrium strategy with observed data. Using laboratory data, we demonstrate that our framework can accurately recover latent parameters across various settings. This capability allows us to analyze scenarios previously unexplored, thus providing a novel tool to infer valuations from bid data.

Bandit Algorithms in Oligopoly Pricing

Julius Durmann, Matthias Oberlechner, Martin Bichler
Technical University of Munich, Germany; julius.durmann@tum.de

Automated algorithms are increasingly used for decision-making, raising questions about potentially harmful outcomes such as reduced customer welfare. Cooperation by algorithms in the pricing context is known as tacit or algorithmic collusion.

In the light of algorithmic pricing, recent findings suggest that Reinforcement Learning algorithms such as Q-learning tend to set prices above the Nash equilibrium level.

We analyze the behavior of simple independent online learning algorithms with bandit feedback in Bertrand oligopolies. The agents compete repeatedly against each other by setting prices and update their beliefs about the market and their actions over time.

Our empirical observations suggest that most bandit algorithms reliably converge to prices at or close to the Nash equilibrium. In particular, signs of collusion vanish when pairing different algorithms. In line with these findings, we can provide convergence guarantees for the class of mean-based algorithms in some oligopoly pricing models. These findings indicate that multiple independent learners can approximate certain Nash equilibria of this class of games.

On the Smoothed Complexity of Combinatorial Local Search

Yiannis Giannakopoulos[1], Alexander Grosz[2], Themistoklis Melissourgos[3]
[1]University of Glasgow; [2]Technical University of Munich; [3]University of Essex; alexander.grosz@tum.de

We propose a unifying framework for smoothed analysis of combinatorial local optimization problems, and show how a diverse selection of problems within the complexity class PLS can be cast within this model. This abstraction allows us to identify key structural properties, and corresponding parameters, that determine the smoothed running time of local search dynamics. We formalize this via a black-box tool that provides concrete bounds on the expected maximum number of steps needed until local search reaches an exact local optimum. This bound is particularly strong, in the sense that it holds for any starting feasible solution, any choice of pivoting rule, and does not rely on the choice of specific noise distributions that are applied on the input, but it is parameterized by just a global upper bound φ on the probability density. The power of this tool can be demonstrated by instantiating it for various PLS-hard problems of interest to derive efficient smoothed running times (as a function of φ and the input size).

Most notably, we focus on the important local optimization problem of finding pure Nash equilibria in Congestion Games, that has not been studied before from a smoothed analysis perspective. Specifically, we propose novel smoothed analysis models for general and Network Congestion Games, under various representations, including explicit, step-function, and polynomial resource latencies. We study PLS-hard instances of these problems and show that their standard local search algorithms run in polynomial smoothed time.

Synergizing Multi-Layer Blockchain Technologies for Enhanced Security and Operational Efficiency

Naiema Shirafkan, Marcus Wiens, Hamed Rajabzadeh, Negar Shaya
Technische Universität Bergakademie Freiberg, Germany; Naiema.shirafkan1@bwl.tu-freiberg.de

This study examines the strategic dynamics of Blockchain Platform Providers (BPPs) and Blockchain Service Providers (BSPs) through a simultaneous move game lens, emphasizing their interactions in the blockchain ecosystem. By analyzing the critical decision variables of pricing and quality of security, we analyze how the actors optimize end-user acquisition and overall profitability. Utilizing Nash equilibrium, the paper identifies optimal strategies that balance competitive pricing with investments in security, a trade-off that is crucial for enhancing platform attractiveness and operational efficiency.

The findings elucidate the pivotal role that strategic interdependencies play in shaping the blockchain environment, with implications for both theoretical exploration and practical application in technology management. By providing a nuanced understanding of the factors that drive decision-making among BPPs and BSPs, this research contributes to the strategic literature on blockchain technology management and offers a foundational perspective for economic actors in this rapidly evolving sector. The paper further discusses the broader implications of these strategies for market competition and technological innovation within the blockchain industry.

TD 12: MCDM Innovations

Time: Thursday, 05/Sept/2024: 2:00pm - 3:30pm · *Location:* Theresianum 2601
Session Chair: Kathrin Klamroth

Quantum Computation Approach in Transmission Expansion Planning

Luca Hofstadler

Austrian Institute of Technology GmbH, Austria; lucahofstadler@live.com

Quantum computation (QC) is an ever more prominent approach to tackling complex optimization problems. In the field of power system engineering, such a challenge is present in the transmission expansion problem (TEP), which gains increasingly interest as the current transmission network urgently needs support in facilitating the growing electricity demand and generation.

TEP involves determining the optimal placement and sizing of new transmission lines to enhance the efficiency and reliability of power grid networks. Currently, the TEP faces a trade-off between reducing the complexity of the model and computational demand. The applied techniques often involve clustering methods to reduce the number of variables of the optimization process, or simplifications in the combinatorics of the selection process for new lines, which QC could address.

There is a lot of ongoing research in TEP and the applicability of quantum computation in the field of power system engineering, but little to no work has been published in terms of QC in TEP. This work consists of a study of the current quantum computation and TEP literature and proposed European TEP projects. The analysis of present TEP methods will enable the identification of use cases and the creation of implementations of QC. The results will be rated based on feasibility, the prediction of computational speed up or allowed increase of complexity through the utilization of quantum properties, or even quantum supremacy.

Optimization-integrated decision problems: an overview

Laura Selicato, Flavia Esposito

University of Bari Aldo Moro, Italy; laura.selicato@uniba.it

Decision-making problems can be formalized as a partition of the set of solutions with respect to an order relation. In this work, we will provide a basic overview of decision-making problems focusing on their formalization as optimization problems. In particular, the partitioning process of these problems involves separating raw information from primitives, which are the fundamental building blocks of the decision model. The decision model is constructed by aggregating preferences that may be multiple, redundant, and conflicting. It is proven that if primitives are expressed on a single attribute, any problem statement results in using an optimization procedure for partitioning the solution set. In real-world scenarios, however, primitives are often expressed on multiple attributes, which raises the question of how to handle such cases. This novel perspective suggests that decision-making problems can be formulated as Multi-Objective Optimization (MOO) problems (if the objectives conflict with each other) or potentially as bi-level optimization problems (if the solution for one objective narrows the search space of solutions for another objective). This approach offers a more comprehensive framework for addressing decision-making problems with multiple attributes, providing a richer understanding of the decision-making process and its applications.

Multiobjective Neural Network Training

Kathrin Klamroth, Fabian Heldmann

University of Wuppertal, Germany; klamroth@uni-wuppertal.de

We discuss a multi-objective perspective on the concept of loss functions in Neural Network training. Rather than considering a weighted sum of different loss terms such as data loss and regularization terms, or data loss and residual loss in Physics Informed Neural Networks, we consider these loss terms as independent and conflicting training goals. We suggest a dichotomic scheme to approximate the Pareto front that uses bisection steps whenever the training gets stuck in local minima. We present results for classical image classification tasks as well as for the training of Physics Informed Neural Networks.

TD 13: Nonlinear Optimization

Time: Thursday, 05/Sept/2024: 2:00pm - 3:30pm · *Location:* Theresianum 2607
Session Chair: Tristan Gally

Uno, a next-gen solver for unifying nonlinearly constrained nonconvex optimization

Charlie Vanaret[1], Sven Leyffer[2]

[1]Argonne National Laboratory, USA & ZIB, Germany; [2]Argonne National Laboratory, USA; vanaret@zib.de

Derivative-based iterative methods for nonlinearly constrained nonconvex optimization usually share common algorithmic components, such as strategies for computing a descent direction and mechanisms that promote global convergence. Based on this observation, we introduce an abstract framework with four common ingredients that describes most derivative-based iterative methods and unifies their workflows. We then present Uno, a modular C++ solver that implements our abstract framework and allows the automatic generation of various strategy combinations with no programming effort from the user. Uno is meant to

(1) organize mathematical optimization strategies into a coherent hierarchy;

(2) offer a wide range of efficient and robust methods that can be compared for a given instance;

(3) reduce the cost of development and maintenance of multiple optimization solvers; and

(4) enable researchers to experiment with novel optimization strategies while leveraging established subproblem solvers and interfaces to modeling languages.

We demonstrate that Uno is highly competitive against state-of-the-art solvers such as filterSQP, IPOPT, SNOPT, MINOS, LANCELOT, LOQO and CONOPT on a set of 429 problems from the CUTEst collection.

Uno is available as open-source software under the MIT license at https://github.com/cvanaret/Uno.

BOBILib: Bilevel Optimization (Benchmark) Instance Library

Johannes Thürauf[1], Thomas Kleinert[2], Ivana Ljubić[3], Ted Ralphs[4], Martin Schmidt[1]

[1]Trier University, Germany; [2]Quantagonia; [3]ESSEC Business School of Paris, Cergy-Pontoise, France; [4]Department of Industrial and System Engineering, Lehigh University, Bethlehem, PA, USA; johannes.thuerauf@uni-trier.de

The field of computational mixed-integer linear bilevel optimization made significant advances over the last 15 years. Many new problem classes have been tackled and a significant number of algorithmic techniques have been introduced. Consequently, we can solve new types of or simply larger problems compared to what was possible in the 2000s. However, what was missing up to now, was a well-curated and publicly available test-set of instances that the community can use to develop, test, and compare novel methods. In this talk, we present the Bilevel Optimization Benchmark Instance Library (BOBILib), which aims for filling the above mentioned gap. BOBILib contains over 2000 instances ranging from general mixed-integer linear bilevel problems to specific interdiction problems. In this talk, we will discuss the structure of the library, the type of instances involved, and the data format in which the problems are given.

Solving MINLPs to Global Optimality with FICO Xpress

Tristan Gally

FICO; TristanGally@fico.com

This talk discusses the global optimization capability within FICO Xpress Solver, which allows to solve general mixed-integer nonlinear problems to global optimality. We will explain the internal workings of the solver, its features, and recent performance improvements.

TD 14: Model Lifecycle

Time: Thursday, 05/Sept/2024: 2:00pm - 3:30pm · *Location:* Theresianum 2605
Session Chair: Susanne Heipcke

The Lifecycle of OR Solutions: From Rapid Prototypes to Market Deployment

Justine Broihan, Frederik Fiand

GAMS Software GmbH, Germany; jbroihan@gams.com

This presentation delves into the transformative process of turning rapid prototypes into market-ready operations research (OR) applications, drawing from a variety of real-world projects. We focus on the methodical transition of prototypes to fully developed solutions, addressing recurring challenges and strategic solutions along the way.

We will explore two main areas: implementing effective OR solutions that meet dynamic market needs, and extracting insights crucial for our product development. This approach shapes a toolkit that is robust and adaptable to evolving technologies.

A significant part of our discussion will highlight the importance of rapid prototyping. This agile phase fosters informed discussions with clients, the end-users, guiding the refinement of prototypes to better meet their needs and expectations.

Furthermore, transitioning from a prototype to a mature OR application is a comprehensive development process. It includes enhancing user interfaces, optimizing deployment strategies (like GUI and cloud computing), and ensuring superior computational performance.

By sharing our experiences and best practices, this talk aims to provide participants with strategies to overcome common obstacles in OR project development. Attendees will gain a deeper understanding of how to effectively move from conceptual prototypes to advanced, market-ready applications, aligning with user needs and achieving operational efficiencies.

Convenient Implementation of Python Applications with Xpress Insight

Alexander Biele

Fair Isaac Deutschland GmbH, Germany; alexanderbiele@fico.com

Often Operations Research applications suffer from not being able to quickly show the business impact in an integrated manner. This reduces the number of deployed applications. In this talk I will demonstrate how to reduce the development time, from model implementation, scenario analysis and closing the feedback loop with FICO Xpress Insight.

At the beginning we showcase the seamless deployment of a Python optimization model and transforming it into a fully operational application within Xpress Insight. We demonstrate the latest enhancements in our IDE Xpress Workbench boosting the Python model development experience, such as autocompletion and enhanced debugging views for various data types. Beyond local debugging, we will spotlight remote debugging capabilities, which allows debugging of scenarios while being executed in Xpress Insight on a remote server.

Building, testing, analyzing, and debugging FICO Xpress Mosel projects

Susanne Heipcke, Yves Colombani

FICO, France; susanneheipcke@fico.com

The Xpress Mosel language is used to implement large optimization and analytics projects. Many such projects are deployed as Xpress Insight apps, either on individual software installations or in a cloud-based environment.

To develop, build, deploy, and maintain such a large code base a team of OR specialists typically works in collaboration with other experts (UI specialists, problem domain experts). The availability of a suitable toolset for building, analyzing, and testing the code in a largely automated way is a must nowadays. The Mosel distribution comes with a set of open-source tools supporting these development tasks.

In this talk we review the roles and usage of the different tools to support the operation of enterprise-grade OR applications. We start with the build process (including the generation of online documentation), we then move on to the topics of testing and code analysis (profiling and coverage) and finally debugging. We consider in particular the case of Insight apps.

TD 15: Reverse and Food Supply Chains

Time: Thursday, 05/Sept/2024: 2:00pm - 3:30pm · *Location:* Wirtschaftswissenschaften 0534
Session Chair: Osman Kulak

Optimal Pricing Policies in a Mobile Phone Refurbishment System

Osman Kulak, Martin Grunow
TUM, Germany; osman.kulak@tum.de

The supply chain for mobile phone refurbishment is characterized by a highly stochastic environment. To maximize the long-term average profit of the refurbishment system, we derive the optimal control strategies for procurement, processing, and pricing. We propose a linear programming formulation for a Markov Decision Process that considers the uncertain arrival of multiple-raw materials. The effects of the variabilities of procurement, price and demand, of the processing rate, and of the customers' price sensitivity on the performance are investigated. Our numerical experiments use industry data and lead to important managerial insights for our industry partner.

Interval-based workforce scheduling with qualification asymmetry in food production

Alexander Blume, Nadine Schiebold
Technische Universität Dresden, Germany; alexander.blume1@tu-dresden.de

Amidst the current challenges of the food industry, including an ever-expanding product variety, optimizing planning processes within production becomes imperative. Due to a shortage of skilled workers, heterogeneous qualifications, and interdependencies between departments and employees, efficient workforce assignment is critical. This work studies a real-world worker assignment problem of a German organic food company. The main particularity is the consideration of a heterogeneous workforce regarding employees' qualifications and skill levels. Additionally, this work includes production-based time intervals as well as shift plans. An integer linear program (ILP) is introduced to assign the workforce optimally. The company's primary goal is to use its staff efficiently and avoid needing temporary workers due to insufficient staff or qualifications. Therefore, the objective function minimizes inefficient assignments and the use of temporary workers. The ILP is used to present an employee schedule to the personnel planners as real-world decision support. Additionally, the solutions point out the company's worker assignment potential, revealing staff utilization inefficiencies, qualification shortages, and imbalances.

Deep Reinforcement Learning for Aging Cheese Inventory Management

Alexander Pahr, Anna Kolemesina, Martin Grunow
Technical University of Munich, Germany; alexander.pahr@tum.de

Producers of aging cheese serve multiple demand streams for products with different maturation ages. The distinct taste of these age-differentiated cheeses prevents product substitution, posing unique challenges in production decisions. These involve balancing immediate revenue from selling younger cheeses against potentially higher future earnings from cheeses aged longer. Additionally, managers must deal with uncertainties, as raw milk costs and final product sales prices follow correlated stochastic processes.

Our Markov Decision Process formulation uses Ornstein-Uhlenbeck processes to capture the price dynamics. The action space includes purchasing decisions, i.e., the amount of raw milk transformed into young cheese, and production decisions, i.e., the volumes of different products placed in the sales market. Further, as product labels define age ranges such as "matured for 3-6 months", issuance decisions determine the allocation of stock volumes from specific age classes to individual products.

We propose a novel Deep Reinforcement Learning algorithm that combines Average Policy Optimization with a rolling horizon lookahead heuristic. In numerical experiments, we investigate the effect of price process parameters on near-optimal policies. Our findings suggest that the value of using age ranges on product labels increases with the mean reversion rate of these processes.

TD 16: Picking in Warehouses

Time: Thursday, 05/Sept/2024: 2:00pm - 3:30pm · *Location:* Wirtschaftswissenschaften 0540
Session Chair: Katja Schimmelpfeng

Storage Assignment Strategies for Distinct Product Assortments in Sequential Zone Picking

Sebastian Debold

University Duisburg-Essen, Germany; sebastian.debold@uni-due.de

Sequential zone picking is a strategy to pick items from a warehouse. It is often used if the number of items per order is comparably low, the overall number of items is low and the volume of orders is high. If there are really few different items compared to the order volume, the same item is placed in multiple zones to improve performance. This gives rise to the problem of order routing, which determines for every order where to pick the required items.

In this presentation, we introduce a storage assignment algorithm for sequential zone picking, which is specifically designed for small product assortments by assigning the same SKUs into multiple picking zones. Our algorithm anticipates the necessary routing decision to balance the zone workload efficiently. Based on this approach, we compare three different strategies on how to deal with distinct assortments in a multi-segmented zone picking system.

Let pickers pick their picks: A field study on the effects of task self-selection on job performance and job satisfaction

Fabian Lorson[1], Monika Westphal[2], Andreas Fügener[2], Alexander Hübner[3]

[1]FUTRUE; [2]University of Cologne, Germany; [3]Technical University of Munich; monika.westphal@uni-koeln.de

Today many activities in operations management are automated, but humans still play an important role due to their flexibility. Human-machine interactions need to be managed efficiently to ensure smooth operations. In the standard human-machine interaction at the shop-floor level, machines determine the assignment of tasks, while human workers mainly execute these often repetitive and monotonous tasks.

One downside of such work division is the mental impoverishment of workers, which relates to stagnating productivity and low job satisfaction. We draw on self-determination theory to argue that enabling workers to self-select tasks can resolve these issues. We conduct a field study in a semi-automated warehouse to test if task self-selection improves workers' job performance and job perceptions, compared to automatic task assignment by the machine.

Indeed, we observe an 8.7% increase in workers' job performance; a great result considering the former year-long stagnating productivity. Interestingly, we also observe lower job satisfaction, when "pickers could pick their picks". Follow-up interviews with pickers, shift leaders, and managers revealed that the new system of task self-selection suspended workers' informal work arrangements.

Our study touches upon an important issue in operations management: integrating human-machine interaction into the workplace while ensuring the job does not get too mundane for workers. We discuss the difficulties that may arise while implementing such systems, and show their potential to improve worker productivity.

New Heuristics for Joint Order Selection, Allocation, Batching, and Picking

Leander Schnaars, Alexander Grosz

Technical University of Munich, Germany; leander.schnaars@tum.de

Order picking in warehouses is well known to be one of the most cost-intensive parts of order fulfillment in warehouses, especially in a picker-to-parts setting, while offering vast optimization potential. Joint Order Selection, Allocation, Batching, and Picking is a unique picker-to-parts order picking setting recently proposed by researchers from Zalando. The problem captures constraints and decision processes observed in large-scale warehouses of online retailers. It combines several of the usually disjoint decision layers with a unique goal of achieving an item throughput goal, thus relaxing the usual strict constraint of serving all orders. Due to the typically large problem instances coupled with strong runtime requirements, existing picker-to-parts approaches are not well suited for this setting. We build upon the work of Khan et al. and propose and evaluate several new heuristics, which improve upon the existing algorithms and provide adjustable runtime to performance trade-offs. We further discuss managerial insights obtained from the heuristics' performances.

Research opportunities from a systematic literature review on zone picking

Martin Sauer, Katja Schimmelpfeng

Universität Hohenheim, Germany; m.sauer@uni-hohenheim.de

E-commerce and omnichannel retailing are significantly changing the requirements for ware-houses and order picking. Warehouses must store an increasing variety of stock keeping units (SKUs), while order picking systems (OPSs) must handle higher order volumes of ever smaller orders within continuously shrinking picking and delivery time windows. Literature indicates that these requirements are difficult to achieve in standard OPSs, and instead identifies zone picking systems (ZPSs) as a promising alternative. Zone picking is the partitioning of a picking area into multiple non-overlapping zones, with each zone assigned to an order picker responsible for retrieving the corresponding part of an order. Following from a systematic literature review on zone picking, this presentation describes present variations of ZPSs as well as their strengths and weaknesses. It further illustrates order picking problems regarding ZPSs and presents opportunities for future research, e.g., the inclusion of human factors such as physical fatigue in order picking problems.

TD 17: Online and Disjunctive Scheduling

Time: Thursday, 05/Sept/2024: 2:00pm - 3:30pm · *Location:* Wirtschaftswissenschaften 0544
Session Chair: Léa Blaise

Goal-stable programming in multi-criteria online scheduling

Markus Hilbert[1], Andreas Kleine[1], Andreas Dellnitz[2]

[1]FernUniversität in Hagen, Germany; [2]Leibniz-Fachhochschule, Hannover; markus-andre.hilbert@fernuni-hagen.de

In a time-dynamic setting, job schedules must be continuously reevaluated and possibly adjusted, for instance, in response to changing priorities triggered by significant customer orders. This situation becomes even more challenging in a multi-criteria context where the attainment of multiple conflicting objectives must be managed over a certain time horizon. This is because each scheduling/rescheduling time-step involves calculating multiple efficient solutions, namely optimal schedules, from which one must select a solution for further execution within the planning horizon. In doing so, the selection process should not only be backward-looking but also forward-looking, in order to maintain planning flexibility and to uphold the attainability of desired targets in the future. To facilitate this in a decision-oriented manner, ensuring that overall performance goals are at least approximately achieved by the end of a planning horizon, this presentation discusses the concept of goal-stable programming and its applicability in the context of multi-criteria online scheduling.

Optimal decision support for real-time production & maintenance planning

Michael Geurtsen

Eindhoven University of Technology, Netherlands, The; m.geurtsen@tue.nl

This research addresses the intricate dynamics of planning in industrial settings, traditionally segmented into strategic, tactical, and operational levels. These levels have been effective in guiding long-term goals, medium-term objectives, and short-term operational needs. Recently, the emerging introduction of an execution level has revolutionized production planning by enabling real-time adjustments to cope with unforeseen disruptions, such as machine failures and labor shortages. This adaptive approach enhances resource utilization and ensures smoother execution on the shop floor.

Surprisingly, the realm of maintenance planning has yet to embrace this execution level, despite its potential to significantly improve efficiency and responsiveness, especially in the era of AI and predictive analytics. The persistent separation of production and maintenance planning, lacking synchronous operations, results in notable inefficiencies and resource wastage. Aligning these functions could prevent scenarios where maintenance during peak production times leads to costly downtimes and repairs.

In response to these challenges, this research proposes an innovative framework for real-time maintenance planning, integrating AI-driven maintenance planning and resource allocation strategies. This framework is designed to leverage real-time data to make proactive maintenance decisions along production that minimize disruptions and optimize overall production performance. By aligning maintenance with production processes and employing advanced technologies, this framework aims to significantly enhance the approach industries currently take toward maintenance planning, promoting greater operational efficiency and sustainability.

Disjunctive scheduling using interval decision variables with Hexaly Optimizer

Léa Blaise

Hexaly, France; lblaise@hexaly.com

Hexaly Optimizer is a “model and run” mathematical optimization solver based on various exact and heuristic methods. The presentation will introduce the different components of Hexaly Optimizer’s primal heuristics through disjunctive scheduling problems.

We will first show how its modeling formalism can be used to express various academic and industrial scheduling problems using interval and list decision variables. These models are very compact, which enables the solver to handle even large-scale problems.

Detecting non-overlap constraints in the model provides the solver with valuable information, which can be exploited through various scheduling-specific movements implemented in Hexaly Optimizer’s neighborhood search. However, due to the tightness of precedence and non-overlap constraints in good solutions to disjunctive scheduling problems (Job Shop Scheduling Problem, for example), such a small-neighborhood search alone struggles to obtain good performance.

Hexaly Optimizer overcomes this issue by reinforcing its neighborhood search component with a solution repair algorithm based on constraint propagation. When a move renders the solution infeasible, it is gradually repaired, one constraint at a time, by heuristically shifting the variables just enough to repair. To extend the transformation rather than cancel it, and to ensure the procedure is fast, we impose never to backtrack on a previous decision to increase or decrease a variable’s value.

TD 18: Electricity Market Modelling

Time: Thursday, 05/Sept/2024: 2:00pm - 3:30pm · *Location:* Theresianum 0601
Session Chair: Tobias Jung

Wholesale electricity market modeling with distribution grid constraints

Arne Lilienkamp, Nils Namockel, Oliver Ruhnau
University of Cologne, Germany; arne.lilienkamp@uni-koeln.de

The transition toward net-zero energy systems implies a rise of distributed generators, batteries, and new consumers, including electric vehicles (EVs) and heat pumps. The additional generation, consumption, and flexibility of these assets may substantially impact wholesale electricity markets. This is, however, subject to distribution gird constraints, which have been neglected in existing wholesale market models. Here, we propose to use the “equivalent electricity storage” approach to aggregate individual consumers’ net load and flexibility at distribution grid level, taking underlying grid constraints into account. The local constraints are approximated based on the installed capacity of low-voltage substations in exemplary distribution grids and scaled to the federal level proportionately to the prevalence of settlement structures. We illustratively apply the approach to flexible electric vehicle charging in Germany for a 2035 scenario. We find that considering distribution grid constraints reduces both the volatility and flexibility of electric vehicle charging, affecting wholesale markets. We analyze further implications for the wholesale market equilibrium as well as the value of relaxing distribution grid constraints.

Solving Large-Scale Electricity Market Pricing Problems in Polynomial Time

Mete Şeref Ahunbay, Martin Bichler, Teodora Dobos, Johannes Knörr
Technical University of Munich, Germany; dobos@cit.tum.de

Electricity market operators worldwide use mixed-integer linear programming to solve the allocation problem in wholesale electricity markets. Prices are typically determined based on the duals of relaxed versions of this optimization problem. The resulting outcomes are efficient, but market operators must pay out-of-market uplifts to some market participants and incur a considerable budget deficit that was criticized by regulators. As the share of renewables increases, the number of market participants will grow, leading to larger optimization problems and runtime issues. At the same time, non-convexities will continue to matter, e.g., due to ramping constraints of the generators required to address the variability of renewables or non-convex curtailment costs. We draw on recent theoretical advances in the approximation of competitive equilibrium to compute allocations and prices in electricity markets using convex optimization. The proposed mechanism promises approximate efficiency, no budget deficit, and computational tractability. We present experimental results for this new mechanism in the context of electricity markets, and compare the runtimes, the average efficiency loss of the method, and the uplifts paid with standard pricing rules. We find that the computations with the new algorithm are considerably faster for relevant problem sizes. In general, the computational advantages come at the cost of efficiency losses and a price markup for the demand side. Interestingly, both are small with realistic problem instances. Importantly, the market operator does not incur a budget deficit and the uplifts paid to market participants are significantly lower compared to standard pricing rules.

Trading Energy Storages in the Continuous Intraday Electricity Market Using Stochastic Control

Tobias Jung
Uniper Global Commodities, Germany; tobias.jung@uniper.energy

Energy storage assets such as hydro pump storages or large scale batteries will assume a pivotal role in the future energy landscape. In contrast to conventional generation assets, which largely operate on fixed schedules and can only vary the amount of energy they provide to the grid, storage assets can be dynamically scheduled in real-time and can both provide energy to and take energy from the grid. As a result, they derive a substantial portion of their monetary value from trading in the highly volatile intraday markets.

This creates many interesting challenges for the purpose of pricing and valuation, risk management, and operational trading.

In this talk, we will explore the case of a single battery energy storage system with the goal of maximizing revenue from trading in the continuous intraday market. The trading problem is framed as a stochastic control problem, where we must account for the simultaneous stochastic evolution of all price processes corresponding to the individual settlement periods underlying a day (which can vary from hours to half hours or quarter hours). The technical specifications and constraints specific to the battery system are incorporated as terminal payoff through the boundary conditions. Together, this results in a high-dimensional stochastic control problem with non-linear and complex boundary conditions. To tackle these challenges, we combine numerical methods with machine learning; specifically, the Deep-FBSDE approach under the stochastic maximum principle as proposed in [Ji, Peng, Peng, and Zhang 2022].

TD 19: Decomposition Approaches

Time: Thursday, 05/Sept/2024: 2:00pm - 3:30pm · *Location:* Theresianum 1601
Session Chair: Bartosz Filipecki

Benders Decomposition for the Optimization of Residential Building Portfolio Modernization Roadmaps

Roman Delorme, Marco Lübbecke
Chair of Operations Research, RWTH Aachen University, Germany; delorme@or.rwth-aachen.de

To efficiently transform residential building portfolios, residential building portfolio modernization roadmaps (RBPMRs) are used to provide information about which specific action to take in which building and which time period. Precisely, RBPMRs constitute transitions of individual building energy systems as well as building renovations over a given time horizon while collectively respecting resource constraints at the building portfolio level. We define the problem of determining optimal RBPMRs and present a MILP model for the problem. To accelerate the solving process, we first introduce a Benders decomposition that projects out building energy system operations into Benders subproblems, and subsequently embed a Benders cut separation algorithm into the branch-and-cut process of the commercial MILP solver Gurobi. Our approach employs various acceleration techniques, including constraint modifications, a tailored Benders optimality cut strengthening technique, and a primal construction heuristic for the Benders relaxed master problem. Additionally, we employ an in-out method to enhance the dual bound at the root node. Using data from the German Census, we construct test instances to evaluate the algorithmic implementations on residential building portfolios. Finally, we demonstrate the practical applicability of our optimization approach through a case study involving data from the residential building stock of a German city.

Solving Security-Constrained Optimal Transmission Switching Problems With Busbar Reconfiguration by Using Benders Decomposition

Oliver Gaul, Tim Donkiewicz
RWTH Aachen University, Germany; gaul@or.rwth-aachen.de

The security-constrained optimal transmission switching problem aims to minimize the operational costs of a power system while maintaining N-1 security. Busbar reconfiguration additionally increases the amount of possible topologies by representing the topological behavior of substations. We consider the linearized DC formulation of the problem, with minimal filtering of switching actions or contingencies. We present a Benders decomposition approach to efficiently solve the problem. In the master problem, we solve an optimal transmission switching problem, optimizing switching actions and generator re-dispatches to reduce branch overloads, without considering contingencies. Instead, for each contingency, a power flow subproblem is solved. To that end, switching and generator decisions from the master, as well as the outaged branches of the contingency, are incorporated into a power flow problem. There, the objective is to minimize the severity of branch overloads. Due to the number of subproblems, it can be beneficial to select a subset of all subproblems to solve as well as constraints to add to the master problem. This can reduce the number of subproblems solved, and limits the size of the master problem, while maintaining optimality. We discuss metrics to measure anticipated subproblem and cut relevance, and how to incorporate them into the solving process. The performance of our approaches is evaluated on modified versions of the publically available pglib-opf instances.

SDP Relaxations of Optimal Power Flow with Maximization Objective: Issues and Mitigation

Bartosz Filipecki
University of Pisa, Italy; bartosz.filipecki@unipi.it

The Alternating Current Optimal Power Flow (AC OPF) problem has garnered significant attention in recent years. One promising approach to address this challenge is the Semidefinite Programming (SDP) relaxation of the OPF. In our study, we focus on a hierarchical system of OPF problems related to transmission and distribution networks. Communication between levels involves computing both lower and upper bounds on available power. Specifically, we explore issues arising when computing upper bounds, which involves solving a problem with a maximization objective rather than the standard minimization one. Finally, we propose potential modifications to mitigate these challenges.

TD 20: Portfolio Optimisation and Risk Assessment

Time: Thursday, 05/Sept/2024: 2:00pm - 3:30pm · *Location:* Theresianum ZG 0670
Session Chair: Gerhard-Wilhelm Weber

Optimal model description of finance and human factor indices

Gerhard-Wilhelm Weber[1], Kalayci Betul[2], Purutcuoglu Vilda[3]

[1]Poznan University of Technology, WIZ (FEM), Poland; [2]Middle East Technical University, IAM (UME), Turkey; [3]Middle East Technical University, Department of Statistics, Turkey; gerhard-wilhelm.weber@put.poznan.pl

Economists have conducted research on several empirical phenomena regarding the behavior of individual investors, such as how their emotions and opinions influence their decisions. All those emotions and opinions are described by the word Sentiment. In finance, stochastic changes might occur according to investors sentiment levels. In this study, our main goal is to apply several operational research techniques and analyze these techniques' accuracy. Firstly, we represent the mutual effects between some financial process and investors sentiment with multivariate adaptive regression splines (MARS) model. Furthermore, we consider to extend this model by using distinct data mining techniques and compare the gain in accuracy and computational time with its strong alternatives applied in the analyses of the financial data. Hence, the goal of this study is to compare the forecasting performance of sentiment index by using two-stage MARS-NN (neural network), MARS-RF (random forest), RF-MARS, RF-NN, NN-MARS, and NN-RF hybrid models. Furthermore, we aim to classify the peoples' feelings about economy according to their confidence levels. Moreover, to forecast the underlying state change of the consumer confidence index (CCI) and to observe the relationship with some macroeconomic data (CPI, GDP and currency rate) at a monthly interval, we apply hidden Markov model (HMM). The aim is to detect the switch between these states and to define a path of these states. We also aim to use volatility models for mainly sentiment index, consumer confidence index, and other indices so that we can get better forecasting results from those datasets.

Diversification Benefits and Hedging Abilities of Crypto Assets in Equities Portfolios

Mario Strassberger

Zittau/Goerlitz University of Applied Sciences, Germany; m.strassberger@hszg.de

This study examines the diversification benefits and hedging abilities of cryptocurrencies like Bitcoin for German stock market investors. From an economic perspective, cryptocurrencies are interpreted as an additional asset class and incorporated into portfolios of equities. Using German stock market data and Bitcoin data from January 2012 to December 2022, the yearly addition of Bitcoin to different long equities portfolios is analysed. To ensure the independence of the results from assumptions regarding investors' risk preferences, portfolios of equities and Bitcoin were constructed with the same projected standard deviation of return as for the pure stock portfolio. Performance measures, such as the reward-to-variability ratio, and risk measures, such as the one-sided Value-at-Risk, were applied to the portfolios created. Furthermore, Bitcoin was employed as a means of hedging equities, with the objective of mitigating the impact of positive and negative stock market movements. In this section, multiple regressions are estimated. The findings indicate that portfolios comprising equities and Bitcoin exhibit enhanced performance relative to portfolios comprising equities alone. However, the limited efficacy of Bitcoin as a means of absorbing market downturns suggests that it may not be an optimal solution for absorbing market volatility. Consequently, while Bitcoin can provide substantially enhanced portfolio risk-return exposures, it is constrained in its ability to act as an efficient hedge to the stock market. Subsequently, we examine the safe haven properties of Bitcoin.

Quantum Annealing: Improving portfolio optimization for insurance companies under solvency, liquidity and ESG considerations

Alexander Dotterweich[1], Tomislav Maras[1], Sebastian Schlütter[2], Nico Piatkowski[3]

[1]PricewaterhouseCoopers GmbH, Actuarial Risk Modelling, Munich, Germany; [2]Mainz University of Applied Sciences, Germany; [3]Fraunhofer IAIS, Media Engineering, Sankt Augustin, Germany; sebastian.schluetter@hs-mainz.de

Quantum computing (QC) is attracting increasing attention as a potential portfolio optimization tool for institutional investors. To understand the implications of QC for investors' portfolio allocation, it is to recognise that QC heralds a fundamental shift in the specification of the problem. Traditionally, portfolio optimization problems have been approached predominantly with continuous specifications, due to the accessibility of efficient solvers even in high-dimensional spaces. However, discrete formulations have attracted attention due to their inherent advantages, including the ability to address cardinality constraints, logical constraints, and incorporate transaction costs. The potential benefits of discrete specification have been hampered by computational difficulties, as these problems are typically NP-hard to solve. With QC operating in binary variables, which can be easily extended to discrete problems, and its potential scalability to large dimensions, QC emerges as a promising bridge between these two approaches to portfolio optimization. This paper explores the differences between classical continuous optimisation methods and QC. It presents the first academic application of QC to a multi-objective investment problem involving preferences for sustainable investments and regulatory capital requirements for insurance companies. Using a comprehensive empirical dataset covering stocks from Europe, the US and Asia, our results suggest a promising potential of QC for institutional investors managing multiple objectives and transaction costs.

Empowering Future Generations: An Innovative Credit Scoring and Risk Assessment Model for Education and Consumer Microloans Tailored to Students and New Graduates

Wichai Witayakiattilerd

Thammasat University, Thailand; wichai@mathstat.sci.tu.ac.th

This research investigates the factors used in calculating credit scores for assessing educational and consumer microloans offered to students and recent graduates within two years of completion. The study aims to develop a credit scoring model by gathering various factors employed in credit score evaluations from existing research and surveys. Subsequently, Factor Analysis is utilized to select appropriate factors and compute the weights of the lending criteria. These factors are then incorporated into a credit scoring model, with the non-performing loan (NPL) ratio and default rate serving as efficiency indices for model evaluation. Additionally, the research simulates loan data, demonstrating the calculation of the index and offering insights on developing and improving the credit scoring model in cases with high NPL ratios and default rates.

TD 21: Railway Applications 3

Time: Thursday, 05/Sept/2024: 2:00pm - 3:30pm · *Location:* Nordgebäude ZG 1070
Session Chair: Stephan Bütikofer

Integrated locomotive and crew scheduling using time-space network formulations

Kanchan Joshi, Jan Ehmke
University of Vienna, Austria; kanchan.joshi@univie.ac.at

The management of locomotives and crew is a crucial tactical planning problem for railways. Due to the complexity of the individual problems, railway companies solve these problems in a sequential manner, i.e. they first generate circulation plans and then shift plans. As a result, the quality of the shift plans depends on the constraints induced by the circulation plan, and information dependencies between both planning steps cannot be exploited. Hence, in this paper, we aim to determine locomotive and driver schedules in an integrated manner. To this end, we minimize the number of locomotives and the number of driver shifts using a time-space network formulation. We investigate the effect of contractual aspects for drivers for both objectives and a cost-based bi-objective formulation. We also consider variants including buffers to determine reliable locomotive and driver schedules. Finally, We present results on the integrated schedules for real-world Austrian railway use cases.

Robust freight train scheduling by allocating pre-constructed slots

Cédric Kekes[1], Franziska Theurich[1], Karl Nachtigall[1], Norman Weik[2], Sara Comelli[2]
[1]Technische Universität Dresden, Germany; [2]Technische Universität München, Germany; cedric.kekes@tu-dresden.de

In the project “Network Capacity” we develop an approach allowing to compute the residual freight capacity for a given passenger timetable, considering freight traffic demand while maintaining punctuality and reliability in operations. This approach combines train scheduling with robustness evaluation based on a (max,+) model for delay propagation. Since timetable-based capacity assessment suffers from fluctuating freight traffic demand, we use pre-constructed slots on net segments which will be combined to train paths as the basis of our model. Precisely, slots are selected and connected to build up conflict-free trains paths for actual freight traffic demand in short-time.

Initially, we construct (possible overlapping) slots for freight traffic fitting into the passenger timetable and considering node capacities. These slots are the basis for routing freight traffic demand. The demand is given as a set of requests, each defined by a source, a destination, a train category and a preferred start time, amongst others. For each, we have to select slots such that they construct a route from source to destination, fits to the train category and preferred start time, and are not in conflict with any other selected slot. Furthermore, several additional constraints have to be hold, e.g. the driving and rest periods for drivers must be considered. The objective is to maximize the freight traffic quality which is compounded by cost-effectiveness and robustness against delays. The resulting optimization problem is close to the Multi-Commodity-Flow-Problem. To solve it, we develop MIP formulations to apply suitable optimization techniques, e.g. Column Generation or Branch-and-Price.

Using a micro-macro transformation for the configuration of the PESP model

Stephan Bütikofer, Valerio De Martinis, Raimond Wuest
Zurich University of Applied Sciences, Switzerland; buts@zhaw.ch

Many railway companies operate with periodic schedules. The periodic event scheduling problem (PESP) was investigated by many different authors and was applied to real-world instances. It has proven its practicability in different case studies.

PESP models normally assume a macroscopic infrastructure, thereby overlooking microscopic details (such as signal positions and switches) that are crucial for precise timetabling. These models often rely on predefined standards for timetabling constraints, like default time values for train separation at stations, which means they cannot ensure the practical feasibility of the timetable. Therefore, macroscopic models need to be enhanced or combined with more microscopic models to guarantee the operational feasibility of the timetable. This leads to complex, time-consuming iterations between the macroscopic and microscopic models.

In the context of an applied research project together with the Swiss Railway Company, we address this problem by combining two well-known approaches.

On one hand, we make use of a known, flexible PESP formulation (FPESP), i.e., we calculate time intervals instead of time points for the arrival resp. departures times at operating points. On the other hand, we will use a micro-macro approach to transform the microscopic data on infrastructure and operation to an aggregated level, i.e. macroscopic. By skilfully integrating the micro-macro approach information into the FPESP model the feasibility of the timetables on the microscopic infrastructure will be enhanced. First numerical results of a small case study will be shown.

TD 22: Last Mile Transportation 2

Time: Thursday, 05/Sept/2024: 2:00pm - 3:30pm · *Location:* Nordgebäude ZG 1080
Session Chair: Stefan Waldherr

On combining conventional door-to-door and pneumatic waste collection systems

Maryam Dehghan Chenary[1], Richard Hartl[1], Stefan Irnich[2], Christian Tilk[1]

[1]University of Vienna, Austria; [2]University of Mainz, Germany; christian.tilk@univie.ac.at

Waste collection systems are an important component of solid waste management systems. Scientific studies have discussed different advantages and disadvantages when employing a single waste collection system. In this talk, we introduce the Combined Waste Collection Problem which combines the two most common waste collection systems: Door-To-Door Collection System, where waste is picked up from households using trucks or other vehicles and Automated Waste Collection Systems, which transport waste from inlets through a network of pipes to a central collection point.

Combined Waste Collection Problem is a two-stage decision problem: First, decide for each customer if she/he is served either with a truck or with the pneumatic system such that the capacity of the pneumatic system is respected. Second, solve a capacitated vehicle routing problem for the truck customers and construct a minimum spanning tree for the tree customers. We present a holistic solution approach based on a set-partitioning formulation utilizing route and tree variables. Since there are exponential many variables, we solve the problem with a column-generation approach. The arising subproblems are an elementary shortest path problem with capacity constraint and a variant of the price-collecting Steiner tree problem.

Multi-day planning in cooperative two-tier city logistics systems with fairness constraints

Johannes Gückel[1], Teodor Gabriel Crainic[2], Pirmin Fontaine[1]

[1]Katholische Universität Eichstätt-Ingolstadt, Germany; [2]Université du Québec à Montréal, Canada; jgueckel@ku.de

The substantial traffic within urban areas poses challenges for both Logistics Service Providers (LSPs) and urban communities. One potential solution to alleviate traffic congestion and maintain cost-effective transport is the implementation of Two-tier City Logistics Systems (2T-CLS).

Given the extensive infrastructure requirements and the presence of multiple LSPs operating within a city, cooperation among these LSPs offers opportunities for both economic and environmental cost savings. However, establishing effective long-term cooperation among LSPs necessitates ensuring that each LSP has incentives to cooperate with others and feels fairly treated. This requires that fairness with regard to the distribution of the workload and the cost is already taken into account in the decision support systems.

Therefore, we introduce a service network design formulation for the planning of cooperative 2T-CLS over a horizon of several days. This formulation includes both workload and cost balance constraints, which can optionally apply either on each individual day or combined over the entire planning period. Moreover, we consider constraints on the limited daily flexibility in selecting services to achieve a certain regularity in the daily schedules.

In a numerical study, we demonstrate that cooperation leads to benefits in the form of cost savings and lower negative environmental impact. In addition, we show that too strict fairness constraints harm the entire coalition and that lower cost increases occur when fairness constraints are enforced over a multi-day period rather than on each individual day.

Pricing and bundling decisions considering driver behavior in crowdsourced delivery

Claudia Archetti[2], Alim Bugra Cinar[1], Markus Leitner[1], Wout Dullaert[1], Stefan Waldherr[1]

[1]Vrije Universiteit Amsterdam; [2]ESSEC Business School of Paris; s.m.g.waldherr@vu.nl

Crowdsourced delivery utilizes the services of independent actors. As opposed to traditional modes of delivery, availability and acceptance decisions of crowdshippers are uncertain and cannot be fully controlled by an operator. We consider a setting in which an operator groups tasks into bundles and in which the resulting bundles are offered to crowdshippers in exchange for some compensation. Uncertainty in the crowdshippers' behavior who may accept or reject offers is considered via (individual) acceptance probabilities.

We introduce and study a model considering individual compensations that influence the acceptance behavior of occasional drivers. We model the latter via probability functions that estimate the likelihood of an occasional driver accepting a task based on available (historical) data, attributes of occasional drivers and tasks, as well as the offered compensation. We propose a mixed-integer non-linear programming (MINLP) formulation that simultaneously decides how to group tasks into bundles, which bundles are offered to which crowdshipper, and the compensation offered for each bundle. Our work is the first study to integrate compensation-dependent acceptance decisions in an exact solution method while also considering the option of offering bundles of tasks to individual drivers, minimizing the combined total expected cost of delivery and compensation.

We show that this MINLP can be reformulated as a mixed-integer linear program with an exponential number of variables. We present a column generation algorithm for solving instances of the latter. Our experiments show that the algorithm is capable of solving large instances.

Solving Very Large-Scale Two-Echelon Location Routing Problems in City Logistics

Banu Ulusoy Dereli[1], Gerhard Hiermann[1], Maximilian Schiffer[1,2]

[1]School of Management, Technical University of Munich; [2]Munich Data Science Institute, Technical University of Munich; banu.dereli@tum.de

With increasing e-commerce transactions and traffic congestion, handling large volumes of parcel deliveries efficiently in city logistics becomes more challenging. To this end, we aim to design a two-echelon distribution system where trucks, originating from a central depot outside the city center, deliver parcels to micro-depots in the city center. Smaller vehicles like cargo bikes handle customer deliveries from these micro-depots. We decide on the location of micro-depots, first-level routes of trucks from the central depot to the micro-depots, and second-level routes of cargo bikes from the micro-depots to customers to minimize the total costs incurred. Our model can also be adapted to allow direct shipment from the central depot to the customers.

From the perspective of a logistics service provider, it is essential to find a good distribution plan quickly for thousands of deliveries. To solve such large-scale problems efficiently, we propose a metaheuristic that integrates a set cover problem with an adaptive large neighborhood search (ALNS) algorithm. Our ALNS approach generates a set of promising routes and micro-depot locations in destroy and repair combined with a local search. We then utilize the set cover problem to find better network configurations during our search. We also develop a decomposition-based cluster-first, route-second approach to solve large-scale instances efficiently. We compare the decomposition approach with our integrated ALNS in terms of solution quality and runtime. We show the efficacy of our algorithm on well-known benchmark datasets and provide managerial insights based on a case study for the city of Munich.

TD 23: Ride Hailing and On Demand Transportation

Time: Thursday, 05/Sept/2024: 2:00pm - 3:30pm · *Location:* Nordgebäude ZG 1090
Session Chair: Arne Schulz

Optimizing a ride-hailing system with a mix of on-demand and pre-booked customers under distributional shift

Breno Serrano de Araujo[1], Alexandre Jacquillat[2], Stefan Minner[1,3], Maximilian Schiffer[1,3]

[1]School of Management, Technical University of Munich, Germany; [2]Massachusetts Institute of Technology, Cambridge, MA, USA; [3]Munich Data Science Institute, Technical University of Munich, Germany; breno.serrano@tum.de

We consider a mixed-operation ride-hailing system that offers customers the option to request a ride on-demand or to pre-book it in advance. For time-sensitive customers, pre-booking provides a service guarantee at a price premium. From the operator's perspective, pre-booking allows for planning ahead with higher certainty but may incur the duty to operate unfavorable trips that may even induce a shift in the demand distribution, e.g., in low-demand suburban neighborhoods. So far, the literature on ride-hailing systems mainly focused on the pure on-demand setting, and only a few works investigated the effects of pre-booking, assuming pre-booked rides follow the same distribution as on-demand rides. Against this background, we develop an optimization framework for a mixed-operation ride-hailing system, allowing us to study the trade-offs between higher planning certainty and the rise of unfavorable rides due to shifts in the demand distribution. Accordingly, we propose a two-stage stochastic optimization formulation in which the first-stage problem consists of deciding which pre-booking requests to accept, while the second-stage problem involves assigning vehicles to requests and planning routes in the face of uncertain on-demand requests. We introduce a solution algorithm that combines Bender's decomposition and column generation. We conduct experiments based on the New York City network using historical yellow taxi trip data. We show that greedily accepting all pre-booking requests decreases the operator's profit and increases dead mileage compared to the pure on-demand baseline. In contrast, optimal solutions to our formulation lead to increased profit and higher fleet utilization while maintaining customer service quality.

To start up a start-up – combining operational fulfillment with strategical fleet allocation in on-demand transportation services

Xinwei Chen[2], Marlin Ulmer[1], Barrett Thomas[3]

[1]Otto-von-Guericke Universität Magdeburg, Germany; [2]The University of Tulsa; [3]University of Iowa; marlin.ulmer@ovgu.de

We consider the problem of many on-demand transportation start-ups: how to establish themselves in a new market. When starting, such companies often have limited fleet resources to serve demand in a city. Dependent on the use of the fleet, different service quality is observed in different areas of the city. The service quality impacts the respective growth of demand in each area. Thus, operational fulfillment decisions drive the longer-term demand development. To integrate strategical demand development in the real-time fulfillment operations, we propose two steps. First, we derive analytical insights in the optimal allocation decisions for a stylized problem. Second, we use the insights to shape the training data of a reinforcement learning strategy for operational real-time fulfillment. We show that the combined consideration of real-time effectiveness and long-term strategy is very beneficial. We further show that the careful shaping of training data is essential for successful development of demand.

Insertions with lookahead for dynamic ridepooling services

Arne Schulz[1], Christian Pfeiffer[2]

[1]Helmut-Schmidt-Universität Hamburg, Germany; [2]Universität Hamburg, Germany; arne.schulz@hsu-hh.de

Due to the required reduction of emissions, modern mobility concepts are rapidly evolving. Ridepooling is one of these concepts. Beside the reduction of emissions due to electric vehicles, ridepooling services promise to reduce traffic due to pooling and to increase mobility access especially in suburban areas. In practice, ridepooling services receive customer orders dynamically and thus have to integrate them in the vehicles' tours. In this talk, we discuss an efficient procedure to insert new customer requests into given tours while incorporating possible future customers with the objective to serve as many customer requests as possible over the time horizon.

TE 01: Semiplenary Goebelt

Time: Thursday, 05/Sept/2024: 4:00pm - 5:00pm · *Location:* Audimax
Session Chair: Stefan Minner

SAP Supply Chain Optimization Optimization Methods and Future Usage of Artificial Intelligence for real-world business problems

Mathias Goebelt

SAP, Germany; mathias.goebelt@sap.com

SAP is the leading supplier of Supply Chain Management Software worldwide and offers a broad range of public & private cloud and on-premise solutions for supply chain planning, logistics, manufacturing, product life cycle management, enterprise asset management as well as solutions for more sustainable supply chains. For more than 25 years, optimization algorithms have been an integral part of the SAP Supply Chain solution portfolio.

Applying optimization algorithms to real-world, large-scale supply chains leads to significant challenges from both functional and performance perspective. To rise to this challenge, SAP is using a range of different optimization algorithms depending on the complexity of the underlying problem class, often in combination with (meta-)heuristics for improved scalability and performance.

We give an overview of the algorithms applied to different solution areas as well as examples highlighting the challenges in terms of scope, data volume and scalability of real-world planning problems of SAP customers. Application areas covered include supply chain network planning in SAP Integrated Business Planning (IBP) for Response and Supply, multi-echelon inventory optimization in SAP IBP for Inventory, production planning optimization and detailed scheduling optimization in SAP S/4HANA embedded PP/DS, vehicle scheduling and routing optimization as well as carrier selection optimization in SAP Transportation Management (TM).

To conclude, we provide an outlook on planned future innovations and give insights into current research focus areas. Key topics include the move from batch-oriented to online optimization, the application of quantum computing to real-world optimization problems and the use of Artificial Intelligence (AI).

TE 02: Semiplenary Wallace

Time: Thursday, 05/Sept/2024: 4:00pm - 5:00pm · *Location:* Theresianum 0602
Session Chair: Gudrun Kiesmüller

Modeling with Stochastic Programming

W. Wallace Stein

NHH Bergen, Norway; Stein.Wallace@nhh.no

There are many deep papers on the mathematics and algorithmics of stochastic programming. But why should we, as operations research people, care? The world is stochastic for sure, but does that imply that we need stochastic models to get good decisions? And if we embark on a genuine application, where real money is involved, what are the modeling questions we need to pose? What are the steps we need to take before we arrive at mathematical and algorithmic challenges?

TE 03: Semiplenary Wiegele

Time: Thursday, 05/Sept/2024: 4:00pm - 5:00pm · *Location:* Theresianum 0606
Session Chair: Clemens Thielen

SDP-based Computational Strategies for Combinatorial Optimization

Angelika Wiegele

Universität Klagenfurt, angelika.wiegele@aau.at

Semidefinite Programming (SDP) is an extension of Linear Programming (LP). A matrix-variable is optimized over the intersection of the cone of positive semidefinite matrices with an affine space. It turns out that SDP can provide significantly stronger practical results than LP and that it can be applied in a lot of different areas, like combinatorial optimization, control theory, engineering, or polynomial optimization.

In this talk we will show how to apply SDP to efficiently approximate NP-hard combinatorial optimization problems, like graph partitioning or minimum sum-of-squares clustering. Linked to the question of modeling a problem using semidefinite programming is the question of solving the resulting SDP. Standard methods like interior point algorithms are not applicable already to medium-sized problems due to the number of constraints or the size of the matrix. We will present alternative methods in order to obtain approximate solutions to the SDP in reasonable time and using affordable memory requirements.

FA 02: Equilibrium Learning

Time: Friday, 06/Sept/2024: 8:30am - 9:30am · *Location:* Theresianum 0602
Session Chair: Kai Jungel

Deep Reinforcement Learning for Equilibrium Computation in Multi-Stage Auctions and Contests

Martin Bichler, Nils Kohring, Fabian Raoul Pieroth

Technical University of Munich, Germany; fabian.pieroth@tum.de

We compute equilibrium strategies in multi-stage games with continuous signal and action spaces as they are widely used in the management sciences and economics. Examples include sequential sales via auctions, multi-stage elimination contests, and Stackelberg competitions. In sequential auctions, analysts are required to derive not just single bids but bid functions for all possible signals or values that a bidder might have in multiple stages. Due to the continuity of the signal and action spaces, these bid functions come from an infinite dimensional space. While such models are fundamental to game theory and its applications, equilibrium strategies are rarely known. The resulting system of non-linear differential equations is considered intractable for all but elementary models. This has been limiting progress in game theory and is a barrier to its adoption in the field. We show that Deep Reinforcement Learning and self-play can learn equilibrium bidding strategies for various multi-stage games without making parametric assumptions on the bid function. We find equilibrium in models that have not yet been explored analytically and new asymmetric equilibrium bid functions for established models of sequential auctions. The verification of equilibrium is challenging in such games due to the continuous signal and action spaces. We introduce a verification algorithm and prove that the error of this verifier decreases when considering Lipschitz continuous strategies with increasing levels of discretization and sample sizes.

Fast and accurate approximations of traffic equilibria via structured learning pipelines

Kai Jungel[1], Dario Paccagnan[2], Axel Parmentier[3], Maximilian Schiffer[1,4]

[1]School of Management, Technical University of Munich, Germany; [2]Department of Computing, Imperial College London, United Kingdom; [3]CERMICS, École des Ponts, France; [4]Munich Data Science Institute, Technical University of Munich, Germany; kai.jungel@tum.de

Growing urbanization and increasing traffic volumes give rise to the need for smart traffic control systems to mitigate the negative externalities of traffic. Recently, many learning-based traffic control systems evolved, which either learn via self-play or require, at minimum, many training data points to achieve a good performance. Generating such data points or system responses via computationally costly traffic simulations hampers the development of the respective algorithms. Against this background, we present a deep structured learning pipeline that allows predicting system equilibria for traffic assignment problems with significantly reduced computational effort. This pipeline comprises a machine learning (ML)-layer and a combinatorial optimization (CO)-layer. The ML-layer receives as input the system state and predicts the parameterization of an equilibrium problem, e.g., latency functions. The CO-layer solves the parameterized equilibrium problem and outputs the system equilibrium. Central to successfully applying this pipeline is training the ML-layer such that the CO-layer outputs good equilibria. To do so, we train the ML-layer on historical data by minimizing a fenchel-young loss. Minimizing the fenchel-young loss reduces the equilibrium error induced by the ML-layer prediction. We study various algorithmic architectures within our pipeline, e.g., learning the costs of multi-commodity flow problems or learning latency functions of wardrop equilibria problems. In this work, we demonstrate the performance of our pipeline by predicting traffic assignments for stylized experiments and outputs from the traffic simulation software MATSim. Our experiments reveal that our pipeline reduces the prediction error by around 70% on average compared to supervised learning approaches.

FA 04: New Approaches to Optimization under Uncertainty 2

Time: Friday, 06/Sept/2024: 8:30am - 9:30am · *Location:* Wienandsbau 2999
Session Chair: Boyung Jürgens

Explorable Uncertainty in Routing

Caroline Spieckermann, Christoph Kerscher, Stefan Minner
Technical University of Munich, Germany; caroline.spieckermann@tum.de

Planning in logistics and transportation is oftentimes complicated by a high degree of uncertainty about the actual travel distances, times, or costs. While stochastic optimization is concerned with making optimal decisions under such uncertainty, it disregards that in many practical applications, uncertainty can be reduced upfront through research and tests, also known as "explorable uncertainty". However, while uncertainty reduction through exploration can improve decision-making, it oftentimes comes at a cost, and one needs to balance exploration costs and solution quality. We study the vehicle routing problem with time windows (VRPTW) and stochastic travel times where uncertainty about travel times can be reduced by making queries to a traffic data provider while respecting an overall querying budget. This converts the stochastic VRPTW into a partially deterministic problem that we solve via point-based approximation and sample average approximation to deal with the remaining uncertainty. We present different methods to make good and fast querying decisions based on statistical features and learning and show their effectiveness in an extensive numerical study. By assuming different degrees of uncertainty, correlations, and time-window restrictions, we give detailed insights into the value of uncertainty exploration in routing.

Decision-Based vs. Distribution-Driven Clustering for Stochastic Energy System Design Optimization

Boyung Jürgens, Hagen Seele, Hendrik Schricker, Christiane Reinert, Niklas von der Assen
RWTH Aachen University, Institute of Technical Thermodynamics, Schinkelstraße 8, 52062, Aachen, Germany; boyung.juergens@ltt.rwth-aachen.de

Stochastic programming is widely used for energy system design optimization under uncertainty, but its computational demand can increase exponentially with the number of scenarios. Common scenario reduction techniques, like moments-matching or distribution-driven clustering, pre-select representative scenarios based on input parameters. In contrast, decision-based clustering groups scenarios by similarity in resulting model decisions. Although decision-based clustering has shown promise in network design and fleet planning, its utility in industrial energy system design remains unexplored.

To address this, we examine the effectiveness of decision-based clustering in energy system design using a four-step method: 1) Determining the optimal design for each scenario; 2) Selecting features reflecting optimal decisions, such as installed capacities or total cost; 3) Using these features for k-medoids clustering to identify representative scenarios; 4) Utilizing these scenarios in stochastic programming.

We apply our method to a real-world case study describing a sector-coupled industrial energy system with a superstructure comprising 20 components, modeled as mixed-integer linear program. We generate 1000 single-year scenarios via Monte Carlo sampling, which we reduce using decision-based clustering. For benchmarking, we conduct distribution-driven k-medoids clustering based on the input parameters. Our results indicate that decision-based clustering provides better designs compared to distribution-driven clustering when dealing with numerous uncertain parameters with low influence on model decisions. However, distribution-driven clustering performs better when only key influential uncertain parameters are present. To our knowledge, this is the first application of decision-based clustering on energy system design optimization, suggesting it can potentially yield better designs with the same number of clusters.

FA 06: Partitioning Problems

Time: Friday, 06/Sept/2024: 8:30am - 9:30am · *Location:* Wirtschaftswissenschaften Z534
Session Chair: Peilin Chen

Round-up Properties for the Length-constrained Cycle Partition Problem

Kilian Til Runnwerth[1], **Ambros Gleixner**[1,2], **Mohammed Ghannam**[2]

[1]Hochschule für Technik und Wirtschaft Berlin, Germany; [2]Zuse Institute Berlin; kilian.runnwerth@student.htw-berlin.de

The length-constrained cycle partition problem (LCCP) is a graph optimization problem where the goal is to partition the set of nodes into as few cycles as possible. Each node is linked to a critical time and the length of a cycle must not exceed the critical time of any node in it. We formulate the LCCP as a set partitioning problem (SPP), which can be solved to global optimality by branch and price. For the SPP, we observe on standard benchmark instances from the literature a consistently small absolute gap between the root node relaxation and the optimal primal bound seemingly observing a round-up property. We say that a problem has the integer round-up property (IRUP) if the objective value of the relaxation of an integer program (IP) rounded up is equal to the optimal objective value of the IP. In this paper we investigate if the LCCP has the IRUP and the relaxed modified IRUP (MIRUP). We define several classes of LCCP with the IRUP, and provide counterexamples with small coefficients for the general case. Additionally, we present a computational study investigating whether the MIRUP holds for the SPP on randomly generated instances.

Forest-based formulation for the balanced connected k-partition problem

Peilin Chen, **Xulin Wang**, **Xin Shu**, **Pan Wang**

Bytedance, China, People's Republic of; peilin.chen@bytedance.com

Partitioning a graph into a fixed number of connected subgraphs with approximately equal weights is a fundamental problem in the fields of graph theory and combinatorial optimization. This problem finds applications in various domains such as farmland allocation, political districting, and sales territory design. However, existing mixed-integer programming (MIP) formulations for this problem struggle to handle large-scale problems, particularly as the number of required subgraphs increases, thereby limiting their practical applicability in real-world scenarios.

In this paper, we propose a more compact forest-based formulation for this problem and validate its efficiency and scalability through computational experiments. It has been integrated into our sales territory design system.

FA 07: Graphs and Steiner Trees

Time: Friday, 06/Sept/2024: 8:30am - 9:30am · *Location:* Wirtschaftswissenschaften Z536
Session Chair: Christoph Geis

Continuous Global Routing

Daniel Blankenburg[1], Stefan Rabenstein[1], Pietro Saccardi[2]
[1]University of Bonn, Germany; [2]formerly University of Bonn, Germany; blankenburg@dm.uni-bonn.de

Global routing in VLSI design involves connecting chip objects with wires through rectilinear Steiner trees, subject to various constraints and optimization goals.

It aims for a solution close to a feasible (detailed) routing while relaxing design rule constraints.

Traditionally, global routing is modeled as a Steiner tree packing problem in a 3D grid graph subject to capacities on the edges. In this model, all objects are mapped to nodes of this coarse grid graph, neglecting the fact that connections to the detailed pin shapes need to be made.

An alternative approach, first introduced by Hähnle and Saccardi, uses uniform rhomboidal tiles to cover the chip area and assigns each tile a capacity for metal object area. Here, too, the global routing problem is a Steiner tree packing problem, but with no wire or pin position restrictions and considering tile area capacities instead of edge capacities. Wire space utilization is measured according to the intersection length with the rhomboidal tiles.

We extend the model of Hähnle and Saccardi by introducing continuous costs for vias (segments that connect consecutive layers of a chip) and we provide a polyhedral description of rectilinear graphs with a fixed structure and their rhomboidal usages.

Using this description, we derive a proof that minimum cost Steiner trees, rather than paths, lie on the rhomboidal Hanan grid.

Further, we extend goal-oriented path search techniques to the rhomboidal model.

The competitiveness of this continuous routing approach is demonstrated by comparing detailed routing results to an industrial traditional global router.

On the Covering of Graphs of bounded Cycolomatic Number with Preselected Paths

Christoph Geis, Sven O. Krumke
Rheinland Pfälzische Technische Universität Kaiserslautern-Landau, Germany; c.geis@math.rptu.de

We consider a special case of the set cover problem which we call the Preselected Path Multi-Cover problem. In this problem, we are given a graph with demands on the vertices as well as a family of paths with capacities and cost. Our goal is finding a minimum-cost multisubset of these paths that cover the demands of all vertices. It is known that this problem is APX-hard even on trees. We consider the problem on graphs that become trees if a constant number of edges is removed. The minimum number of edges we need to remove to turn a graph into a forest is called the cyclomatic number. We give a 5-approximation algorithm for Preselected Path Multi-Cover on graphs with bounded cyclomatic number. Furthermore, we give a 5log(k)-approximation algorithm, where k is the cyclomatic number, with a runtime independent of k. For the latter algorithm, we modify the greedy algorithm for Set Multicover so it can deal with having convex instead of linear costs on singlet sets only. This modified greedy algorithm may be of independent interest.

FA 08: Novel Approaches for MINLP

Time: Friday, 06/Sept/2024: 8:30am - 9:30am · *Location:* Wirtschaftswissenschaften Z538
Session Chair: Ivo Nowak

All You Need is a Paraboloid: A Novel Approach to Nonlinear Programming

Adrian Göß, Robert Burlacu, Alexander Martin

University of Technology Nuremberg (UTN); adrian.goess@utn.de

It is only half the battle to find a good solution in mathematical optimization, as one needs to verify its quality by specifying a dual bound. When it comes to (mixed-integer) nonlinear programming ((MI)NLP), strong prerequisites such as constraint qualifications appear suitable for this, but may be difficult to verify computationally. In practice, solvers apply local refinement (e.g., piecewise linear approximations, spatial branching) or convexification strategies (e.g., alpha-Branch-and-Bound) to retrieve tight dual bounds. However, these concepts require appropriate big-M formulations, generate new sub-problems, or struggle to represent non-convex characteristics in terms of high accuracy, all of which can lead to long running times. As an alternative, we aim to leverage recent advances in (mixed-integer) quadratically-constrained programming ((MI)QCP) and propose a global approximation of constraint functions by paraboloids, i.e., univariate quadratic terms. In particular, for each nonlinear constraint function, a binary search is applied to determine small numbers of paraboloids approximating it from either side if necessary. This leads to a relaxation of the original problem, namely to a quadratically constrained one. A solution of the latter then leads to a dual bound whose tightness depends on the approximation guarantee of the paraboloids. In summary, this motivates to solve (MI)NLP problems with solvers explicitly tailored to (MI)QCP problems.

On Model Generation and Decomposition for Global Optimization, Control and Machine Learning

Ivo Nowak

HAW Hamburg, Germany; ivo.nowak@haw-hamburg.de

We present decomposition-based methods for generating reformuations of complex optimization and control problems that can be solved easier than the original problem. The methods are implemented in the open-source frameworks Decogo and Decolearn. Numerical results for nonconvex MINLPs and machine learning problems are presented.

FA 09: E-Grocery Management

Time: Friday, 06/Sept/2024: 8:30am - 9:30am · *Location:* Wirtschaftswissenschaften Z532
Session Chair: Charlotte Köhler

Subscription-Based Inventory Planning for E-Grocery Retailing

David Winkelmann[1], Charlotte Köhler[2]

[1]Bielefeld University, Germany; [2]European University Viadrina, Frankfurt (Oder), Germany; david.winkelmann@uni-bielefeld.de

The growing e-grocery sector faces challenges in becoming profitable due to heightened customer expectations and logistical complexities. This paper addresses the impact of uncertainty in customer demand on inventory planning for online grocery retailers. Given the perishable nature of grocery products and intense market competition, retailers must ensure product availability while minimising overstocking costs. We propose introducing subscription offers as a solution to mitigate these inventory challenges. Unlike existing literature focusing on uniform subscription models that may harm profitability, our approach considers the synergy between implementing product subscriptions and cost savings from improved inventory planning. We present a three-step procedure enabling retailers to understand uncertainty costs, quantify the value of gathering additional planning information, and implement profitability-enhancing subscription offers. This holistic approach ensures the development of sustainable subscription models in the e-grocery domain.

In-store order picking for e-grocery

Charlotte Köhler[1], Jan Fabian Ehmke[2], Ann Melissa Campbell[3]

[1]Europa-Universität Viadrina, Germany; [2]Universität Wien, Austria; [3]University of Iowa, United States; koehler@europa-uni.de

E-grocers struggle to create profitable business models, and careful planning is needed to balance tight margins with high customer expectations. Although numerous studies emphasize optimizing customer acceptance and efficient delivery, the costs and resources required for picking orders are less examined despite their significant influence on profitability.

In this presentation, we delve into in-store picking costs within the e-grocery context and introduce a cost evaluation function designed to give retailers a precise assessment of the resources needed for picking orders, thereby assessing feasibility and maximizing the number of accepted orders. For e-grocers, the time taken to pick items is a critical determinant of costs and use of resources, as longer picking times directly translate to increased labor expenses and fewer orders that can be picked.

We are conducting a comprehensive assessment of the proposed cost evaluation function, utilizing real-world data to ensure accuracy and relevance for different order picking strategies. Our assessment employs a detailed analysis of store layouts like those of REWE in Germany, combined with historical data from a former German e-grocer involving over 400,000 order baskets. This data provides insights into typical order compositions and the resources needed for various basket types, enhancing our understanding of critical costs in e-grocery picking. The insights from this study will provide valuable input for a comprehensive analysis of both picking and delivery processes in the e-grocery sector.

FA 10: Logistics and Rescue in Healthcare

Time: Friday, 06/Sept/2024: 8:30am - 9:30am · *Location:* Wirtschaftswissenschaften 0514
Session Chair: Somayeh Allahyari

UAV Search on a Network of Regions

Ertan Yakici[1], Mumtaz Karatas[2], Levent Eriskin[3], Orhan Karasakal[1]

[1]Cankaya University, Turkiye; [2]Wright State University, OH, USA; [3]Piri Reis University, Turkiye; eyakici@cankaya.edu.tr

Unmanned Aerial Vehicles (UAVs), with their flight capabilities such as range, endurance, and altitude, have increased the capabilities of both military power and organizations performing operations such as search and rescue. UAVs can easily accomplish tasks that are difficult and unsafe for conventional aircraft, such as discovering or destroying chemical, biological, and nuclear facilities or highly defended combat platforms on land or at sea. Effective planning for the use of resources with high technological capabilities is as important as developing and employing them. The problem addressed in this study assumes the presence of threatening elements in various regions with specific probabilities. The study involves deploying a UAV fleet to search these regions within a network, each with different levels of search challenges, all within a constrained operational timeframe. The search for detection in each region follows the assumptions of random search, where the time to detection is a random variable of exponential distribution with a certain mean. The mathematical model developed for the problem attempts to create a search plan that maximizes the total detection probability of threats continuously throughout the time from the start to the end of the operation. Within this plan, decisions such as determining deployment points (bases) for each UAV in the fleet, determining the regions to be searched and the search times for each UAV, and determining the search sequence among these regions will be simultaneously optimized. A heuristic solution approach is suggested for the instances that are large in size and need to be solved quickly.

Blockchain and Truck-Drone Routing Synergies to Enhance Last-Mile Medical Logistics

Somayeh Allahyari, Keru Duan, Gu Pang

University of Birmingham, United Kingdom; s.allahyari@bham.ac.uk

The efficiency of last-mile delivery in medical logistics is critical, particularly when delivering urgent medical supplies such as pathology specimens, vaccines, test kits, and emergency medication. The integration of advanced technologies like blockchain and unmanned aerial vehicles, commonly known as drones, presents a promising solution to enhance these operations. Given the critical need for secure, tamper-proof data handling of medical items, blockchain technology is employed to ensure data integrity, real-time tracking, and compliance with health regulations. We introduce a novel two-echelon truck and drone routing problem model within a blockchain-managed network. This study aims to leverage the speed and flexibility of drones, combined with the security and transparency of blockchain technology, to streamline medical logistics operations and enhance the responsiveness and reliability of medical supply chains. For this problem, we develop a mixed integer linear programming formulation along with a metaheuristic algorithm designed to efficiently handle large data instances. The implementation of our model in a simulated urban environment not only shows a significant reduction in delivery times and operational costs compared to traditional vehicle-based logistics solutions but also enhances data security and improves the traceability of medical shipments, providing a reliable audit trail throughout transportation.

FA 12: Data Envelopment Analysis

Time: Friday, 06/Sept/2024: 8:30am - 9:30am · *Location:* Theresianum 2601
Session Chair: Xu Wang

Enhanced Customer Segmentation and Ranking Using Super Efficiency Data Envelopment Analysis

Yossi Hadad, Baruch Keren

SCE - Shamoon College of Engineering, Israel; yossi@sce.ac.il

Many organizations employ unique segmentation and customer evaluation methods to allocate appropriate managerial attention to each segment and individual customer. This presentation introduces an enhanced objective method for segmenting and comprehensively ranking customers. The proposed approach utilizes customer criteria with quantitative values derived from the organization's information system. Customer scores are determined objectively using Super Efficiency (SE), a ranking technique within Data Envelopment Analysis (DEA). This method allows tracking of each customer's relative position within their segment (e.g., Platinum, Gold, Silver, and Bronze) over time. It provides a precise, complete ranking based on company-defined criteria. The effectiveness of the proposed method was demonstrated through a real-world case study.

Least-distance DEA Approach for Efficiency Evaluation and Benchmarking

Xu Wang, Takashi Hasuike

Waseda University, Japan; xu.wang@aoni.waseda.jp

Data Envelopment Analysis (DEA) is widely used to evaluate the relative efficiency of decision making units (DMUs), including banks, hospitals, schools, and more, and provide benchmarking information (efficient targets) for them in operations research. In DEA, two common frameworks are employed for efficiency evaluation and target setting (benchmarking): the greatest-distance and least-distance frameworks. The greatest-distance framework identifies the farthest efficient target for the DMU under evaluation, essentially seeking an efficient target that suggests maximum improvements to achieve efficiency. Conversely, the least-distance framework aims to find the closest efficient target for the DMU under evaluation, seeking an efficient target that is most similar to the DMU under evaluation. This approach is often preferred as it provides a more attainable benchmark for improving the performance of inefficient DMUs.

In this research, we will introduce the operation of both conventional DEA models (referring to those based on the greatest-distance framework) and the least-distance DEA model to demonstrate the practicality of the closest efficient target. Additionally, we will present our newly proposed effective Mixed Integer Programming (MIP) approach for computing the closest efficient target. Furthermore, we will introduce a new DEA model called "Least-distance Range Adjusted Measure (LRAM)" for efficiency evaluation and benchmarking.

FA 13: OR Case Studies

Time: Friday, 06/Sept/2024: 8:30am - 9:30am · *Location:* Theresianum 2605
Session Chair: Christoph Hofer-Temmel

BL.Optim: an OptaPlanner based optimizer towards resolution of large-scale realistic scheduling and routing problems

Liwen Zhang, Sara Maqrot, Florent Mouysset, Christophe Bortolaso
Research and Innovation Unit, Berger-Levrault, France; liwen.zhang@berger-levrault.com

Nowadays, a diverse range of business sectors necessitates the development of optimal planning that aligns with various business-oriented objectives and constraints Consequently, generating scheduling and routing solutions for organizational staff has become exceedingly complex, especially with large-scale realistic problems. Optimization models play a vital role in assisting organizational decision-makers for addressing operational challenges and generating satisfactory solutions using powerful optimizers. This research work tackles the challenges associated with realistic Scheduling and Routing Problems (SRPs) with a multi-day horizon. To address these challenges, BL.Optim is introduced, which is an OptaPlanner-based optimizer with a model-based architecture. BL.Optim aims to capture routing and scheduling requirements for a wide category of Constraint Satisfaction Problems (CSP), with customizable requirements that can activate necessary constraints according to specific realistic use cases. A set of pre-formulated CSP-based soft constraints and non-violated hard constraints are embedded within BL.Optim. To assess the optimality of solutions generated by BL.Optim, two real-life use cases of Preventive Maintenance SRPs in Spain and France are presented, involving up to 481 activities to be performed by 18 staff members over 4 weeks. These use cases are tested in BL.Optim under different metaheuristic configurations (e.g., tabu search), and the solution scores are compared. Experimental results demonstrate high-quality optimized solutions free from hard constraint violations and with minimal penalties for soft constraints, achieved within a short computing time of just 8 minutes.

Functional programming, OR algorithms and power trading: a case study

Christoph Hofer-Temmel
illwerke vkw; christoph.hofer-temmel@illwerkevkw.at

We present the architecture and decisions behind the OR framework for energy trading operations in a power-sector company.

With established processes and software ecosystem, there are many path-dependent constraints but also room for some fundamental choices.

We discuss the reasons behind the architectural decisions taken.

In particular, we highlight our experience using a single strongly statically typed functional programming language for all aspects from modelling and algorithm development to deployment and interactive data analysis.

Further points are API and library integration including dependency management (both up- and downstream), documentation vs specification and the ubiquitous datastore for algorithmic IO data.

FA 15: Supply Planning

Time: Friday, 06/Sept/2024: 8:30am - 9:30am · *Location:* Wirtschaftswissenschaften 0534
Session Chair: Maximilian Schön

Robust and reliable forecast tools: Combining Time Series Predictability and Forecast Accuracy

Alina Timmermann, **Sebastian Peitz**

TU Dortmund University, Computer Science Chair IV, Germany; alina.timmermann@tu-dortmund.de

Forecasting in industrial companies remains a challenge in times of rapidly changing environmental conditions that result in increasing uncertainty. Forecasting tasks are more and more replaced by forecast tools. Forecast results must be of highest accuracy as well as trustworthy for the user to successfully replace expert opinions as the standard to lower costs, efforts and resources.

Each forecasting method performs individually well on different types of time series. Thus, for maintaining robust and reliable forecast results, characterizing different time series for choosing the most suitable forecast method becomes a necessary step. One metric for characterizing time series is their chance of successful prediction, called predictability. For calculating predictability of a time series, several methods exist with different type of outcome, such as a continuous number or a binary. A general guideline on usage and comparison of these diverse approaches and their correlation is lacking in literature, especially in combination with forecasts validating the findings.

In our work, we combine seven different approaches for estimating the predictability of time series. We perform these tests on a synthetic benchmark dataset including random time series, linear time series and series with continuous seasonality such as sinus waves, as well as on open-source sales and stock data. For the validation of the predictability metrics with forecasting, diverse forecasting methods and evaluation metrics are used. With our results, we hope to contribute to more robust and reliable forecast tools that work reliably independent of the underlying time series.

Aggregate Production Planning under Risk of Disruption

Maximilian Schön[1,2], **Chenghao Dai[2]**, **Frank Herrmann[1]**, **Thorsten Claus[2]**

[1]Ostbayerische Technische Hochschule Regensburg, Germany; [2]Technische Universität Dresden, Germany;
maximilian1.schoen@st.oth-regensburg.de

In recent years, large scale disruptions to global supply chains, like the Covid pandemic, a ship blocking the Suez canal or sanctions against Russia, have caused production to slow down or even to stand still, causing shortages and massive losses for affected businesses. Even if only specific companies were originally affected, shortages and delays rippled along the supply network.

The established approach to deal with disruptions is to utilize safety stock and capacity to compensate for fluctuations in uncertain quantities like customer demand. This approach is tried and tested for small fluctuations. To address larger disruptions, like the above given, very high safety stock and capacity would be needed, which would lead to unnecessarily high costs.

Resilience has often been viewed as an expensive capability that drives costs. Recent studies however advocate for the development of lean resilience concepts, creating new capabilities, which enable resilience and can deal with large fluctuations, reimagining resilience from the perspectives of efficiency and value creation.

This contribution identifies gaps in current research and establishes structural deficits of approaches discussed in the literature regarding supply chains. Firstly, the need for rigorous, quantitative definitions of resilience and relevant disruptions is justified. Then, a stochastic model for aggregate production planning that includes capabilities to compensate for such large fluctuations along several dimensions is proposed. Lastly, this model is then applied to a case study pertaining to a realistic supply chain under the risk of large scale disruptions and the results of this approach are evaluated.

FA 16: Production Challenges

Time: Friday, 06/Sept/2024: 8:30am - 9:30am · *Location:* Wirtschaftswissenschaften 0540
Session Chair: Antonia Thiemeyer

Solving General Assemble-to-Order systems via Component-Based and Product-Based Decomposition Methods

Mohsen ElHafsi[1], Jianxin Fang[2], Essia Hamouda[3]

[1]University of California-Riverside; [2]Xi'an Jiaotong-Liverpool University (XJTLU), International Business School Suzhou; [3]California State University at San Bernardino, J. H. Brown College of Business; melhafsi@ucr.edu

Assemble-to-order (ATO) strategies are widely used in various industries. Despite their popularity, ATO systems remain challenging, both analytically and computationally. We study a general ATO problem modeled as an infinite horizon Markov decision process. In particular, we consider a system with mixed-Erlang distributed component production/leadtimes, and Poisson demand for products. Demand is lost if not immediately satisfied. As the optimal policy of such system is computationally intractable, we develop two heuristic policies based on decomposition methods: component-based and product-based. In order to evaluate the performance of the heuristics, we develop a tight lower bound using an Approximate Linear Programming approach that relies on a judicial choice of basis-functions, for approximating the optimal value function. Our results show that the heuristics perform within only few Average Percentage Deviation (ADP) from the lower bound and even a smaller ADP when compared to systems where the optimal policy could be obtained. Moreover, we show that our component-based decomposition heuristic only scales linearly with the number of components in the ATO system, and therefore is suitable for solving large-scale ATO systems.

Scheduling maintenance activities subject to stochastic job-dependent machine deterioration

Antonia Thiemeyer

Bergische Universität Wuppertal, Germany; thiemeyer@wiwi.uni-wuppertal.de

A significant proportion of machine scheduling models assume that machines are available over the whole planning horizon without any restrictions. However, in the real world, machines need to be maintained from time to time, which has a direct impact on the processing of jobs. For this reason, we consider machines whose availability depends on their maintenance state.

This talk considers the problem of scheduling maintenance activities (MAs) for a given sequence of jobs on a single machine, with the goal of minimising the expected total completion time. The maintenance state deteriorates as the jobs are processed. Each individual job deteriorates the machine by a certain amount, which is subject to a continuous probability distribution. If the deterioration exceeds the maintenance level, a costly emergency maintenance activity must be performed to repair the machine and ensure that processing can continue.

Further, the single machine under consideration is assumed to be transparent. This means that the current maintenance level of the machine can be read out between any two jobs in the sequence. Therefore, the user can decide whether or not to perform a MA based on the information of the actually realised deteriorations and the resulting maintenance level. The main technique used to develop a decision policy is an approximate dynamic program (ADP). During the talk we will present the developed approach and some numerical results on the performance of the decision policy resulting from the ADP compared to different benchmark policies.

FA 17: Job Shop Scheduling

Time: Friday, 06/Sept/2024: 8:30am - 9:30am · *Location:* Wirtschaftswissenschaften 0544
Session Chair: Felix Buld

Optimization of the Flexible Job Shop Scheduling Problem with Process Time Uncertainty

Yasaman Karimian

TUM, Germany; yasaman.karimian@tum.de

Since production environments have become more dynamic, flexible job-shop scheduling problems have become increasingly significant. Manufacturers have elevated the idea of flexible manufacturing to new heights, exploring the implementation of flexible assembly layouts, also called matrix production systems. This study considers the NP-hard optimization problem of flexible job shop scheduling (FJSP), where automated guided vehicles (AGVs) transport bodywork along individual routes between assembly stations. We propose a mathematical model using mixed integer programming to formulate the problem. The performance of the proposed model is analyzed through a comprehensive analysis and solving test problems. In addition, we extend our study to consider the impact of process time uncertainty on scheduling robustness.

Scheduling with Reentry

Felix Buld, Maximilian von Aspern

TU Munich, Germany; felix.buld@tum.de

We are considering scheduling problems where jobs are required to reenter machines. The presented research focuses on problems where jobs traverse machines in a cyclic loop pattern. We extend previously established work on minimizing the total completion time to minimizing a weighted sum of completion times. We give a structural property about optimal schedules and relate the problem to a parallel machine problem with machine-dependent processing penalties. It allows us to show NP-hardness for the considered scheduling problem with reentry and weighted total completion time objective. Afterward, we analyze an approximation algorithm with a provably small approximation ratio for this problem.

FA 19: Game Theoretical Approaches

Time: Friday, 06/Sept/2024: 8:30am - 9:30am · *Location:* Theresianum 1601
Session Chair: Stefan Kupfer

Developing a game theoretic approach for planning a CO2 pipeline network

Stephan Bogs, Ali Abdelshafy, Grit Walther
RWTH Aachen University, Germany; stephan.bogs@om.rwth-aachen.de

The energy transition demands innovative technologies and infrastructure to achieve carbon neutrality. Due to hard-to-abate emissions and the challenge of securing sufficient renewable energy, many industries must adopt carbon capture and storage (CCS). CCS is essential for mitigating climate change by capturing and permanently storing CO2 emissions that cannot be otherwise eliminated. Herein, a critical aspect of CCS is developing pipeline infrastructure, which efficiently connects CO2 sources to storage sites, offering substantial economies of scale. Efficient pipeline networks are crucial as they maximize the economic benefits and require close collaboration among competing firms, which is often challenging in competitive markets. While system-wide planning for CO2 pipelines has been extensively studied, there is a need for more research on the roles of individual stakeholders.

Building on our established systemic optimization framework, which accurately models pipeline layouts, we introduce a novel game-theoretic approach to plan CO2 pipeline networks on a national scale. We conceptualize this problem setting as both a strategic game and a cooperative, cost-sharing game. We also demonstrate these models by applying them on a case study of the German cement and lime industry. Herein, the analyses illustrate the trade-offs in strategic versus cooperative scenarios. In the cooperative model, we also examine the power imbalance between larger companies, which operate multiple plants and hold greater market share, and smaller, independent producers or groups.

Timing Green Technology Investments in a Duopoly: Voluntary Overcompliance for Tougher Regulation

Stefan Kupfer[1], Verena Hagspiel[2], Elmar Lukas[1]
[1]Otto-von-Guericke-University Magdeburg, Magdeburg, Germany; [2]Norwegian University of Science and Technology, Trondheim, Norway; stefan.kupfer@ovgu.de

We develop a policy game between a regulator and two firms operating in a duopoly, where one firm unilaterally commits to a more environmentally or socially friendly technology to trigger tougher regulation. The other firm has a competitive disadvantage under the new technology regulation and may preempt the threat of future public policy by investing in a hybrid approach, partially using the new technology. We incorporate asymmetric information by assuming that the firms have private information about the true costs of the new technology, unlike the welfare maximizing regulator who only prefers to regulate under low costs. In our dynamic real option game model, investment decisions serve as signals of private cost information to the regulator. Overcompliance of firms with a competitive advantage in the cleaner technology is a signaling for tougher regulation. This signaling incentive distorts timing decisions in the duopoly. If the difference in low and high costs is significant, the advantaged firm must speed up investment to reinforce truthful signaling. The disadvantaged firm tries to preempt its competitor's signal by investing in a hybrid approach, aiming to generate enough welfare to dissuade public action by the regulator. Our model also provides insights into the impact of asymmetric information and the cost structure of old and new technologies on the policy game.

FA 21: Transportation Network Design

Time: Friday, 06/Sept/2024: 8:30am - 9:30am · *Location:* Nordgebäude ZG 1070
Session Chair: Alexander Helber

Long-haul Connected and Autonomous Transportation Network Design

Ebrahim Mohammadi Hosein Hajlou[2], Marie Schmidt[1], Rob Zuidwijk[2]

[1]Universität Würzburg, Germany; [2]Erasmus University Rotterdam, the Netherlands; marie.schmidt@uni-wuerzburg.de

Connected and Autonomous Transportation (CAT) is expected to greatly improve the safety and efficiency of the transportation network. However, CAT requires, for example, road infrastructure, transfer hubs, and fueling stations to be ready for use by autonomous vehicles. In this paper, we investigate the problem of optimally locating such necessary enablers to facilitate CAT transportation.

We introduce a new optimization problem by integrating the location decisions of multiple enablers into a single optimization problem. We present a mixed-integer linear program and a heuristic approach to solve the problem.

In our computational study, we demonstrate the superiority of integrated decision-making over sequential decision-making within this problem setting and show that each enabler induces a rather different network configuration, particularly under limited investment budgets. Our findings suggest that while increased CAT cost benefits might elevate overall travel distances, the potential fuel efficiency of CAT could lead to reduced emissions. Furthermore, introducing financial incentives like tax cuts for CAT users might not significantly boost its uptake in long-haul transportation.

Branch-Price-and-Cut for a Hub Network Design Problem with Line Hauls

Alexander Helber, Marco Lübbecke

RWTH Aachen, Germany; helber@or.rwth-aachen.de

Less-than-truckload freight transport companies reduce transport costs of palette-sized shipments between customers by consolidating shipments at hubs. To transport shipments between hubs, trucks operate a network of multi-stop line hauls. On a strategic level, companies need to plan where to locate hubs and which customers to assign to each hub. These decisions then impact the tactical design of the line haul network. In the literature these two aspects are usually considered separately or the network design is strongly simplified. We consider an integrated problem, solutions to which lead to more cost-effective networks compared to optimizing both aspects individually.

To solve the problem, we propose a branch-price-and-cut approach to dynamically generate line haul variables and constraints connecting the customer assignments with the network design. A variable neighborhood search and various other algorithmic components speed up the solving process. We present computational results of our algorithm and practical insights from the solutions obtained.

FA 22: Bus Transportation

Time: Friday, 06/Sept/2024: 8:30am - 9:30am · *Location:* Nordgebäude ZG 1080
Session Chair: Xenia Haslinger

Multi-Objective Vehicle Scheduling for Intercity Bus Operations with Subcontractors Services

Aron Rudolf Max Lange

TUD Dresden University of Technology, Germany; aron.lange@tu-dresden.de

The Vehicle Scheduling Problem (VSP) represents a pivotal focus within transportation logistics. This study introduces novel practical objectives tailored explicitly for the context of intercity bus operations. The primary objective for VSPs focuses on minimizing fixed costs by minimizing the number of vehicles needed to serve all trips from the timetable. Additionally, the optimization targets reducing operational costs by strategically minimizing deadhead trips and waiting times.

This study introduces innovative metrics pertinent to the complexities of large-scale bus companies, which often rely on subcontractors for service execution. One such objective involves minimizing the number of distinct lines or trips in schedules, particularly crucial in cases where complete lines are entrusted to subcontractors. This strategic approach fosters schedule homogeneity among subcontractors, streamlining operational logistics and simplifying contingency planning in the event of breakdowns.

By preemptively optimizing schedules for subcontractors, bus companies can bolster their negotiating leverage and forge more advantageous partnerships. This paper presents a mixed-integer formulation addressing this multi-objective problem, complemented by a computational analysis of real-world instances. The findings underscore the efficacy of the proposed approach in enhancing operational efficiency and strengthening strategic positioning in intercity bus operations.

Solving practical single- and multi-depot electric bus scheduling problems

Xenia Haslinger[1], Elisabeth Gaar[2], Sophie N. Parragh[1]

[1]Johannes Kepler University Linz, Austria; [2]University of Augsburg, Germany; xenia.haslinger@jku.at

For environmental reasons, bus operators are planning to replace diesel buses with battery-electric ones in public transportation. However, scheduling electric buses is more complicated because of their limited battery capacity and long recharging times. Additionally, they require special charging infrastructure, which generally makes them less flexible than diesel buses.

In this study we address the single- and the multi-depot electric vehicle scheduling problem, in which a set of timetabled bus trips, each starting and ending at particular locations and times, should be carried out by a homogeneous fleet of electric buses. The buses start at their respective depot and return there after carrying out the service trips. Full or partial recharging is allowed either at charging stations located at the depot or at bus stops at the end of the respective service trips.

For the single- and multi-depot electric bus scheduling problem we present a three-index mixed-integer linear program where, in order to support the technology decision, we minimize lexicographically the number of vehicles to cover all timetabled trips, followed by the number of charging events during a day, and finally the energy spent on trips without passengers, so called deadhead trips. We reformulate the 3-index formulations into 2-index formulations and separate constraints of exponential size in a cutting plane fashion.

FA 23: Innovative Applications in Transportation

Time: Friday, 06/Sept/2024: 8:30am - 9:30am · *Location:* Nordgebäude ZG 1090
Session Chair: Tobias Vlćek

Anticipatory Re-Optimization for Courier Services of Medical Specimens

Jarmo Haferkamp, Marlin Ulmer

Otto-von-Guericke-Universität Magdeburg, Germany; jarmo.haferkamp@ovgu.de

During the COVID-19 pandemic, courier services for medical specimens have been crucial to the implementation of large-scale testing programs. Such courier services typically offer different order priorities, i.e., deadlines for the pickup and delivery of specimens to a laboratory. However, as the COVID-19 pandemic has shown, transportation demand can fluctuate dramatically, resulting in promised delivery deadlines may not always be feasible for all orders. To minimize the expected cumulative delay, we propose an anticipatory re-optimization approach by integrating an adaptive Cost Function Approximation (CFA) into a Large Neighborhood Search (LNS). The LNS iteratively optimizes the incumbent route plans upon placement of a new order. The CFA, in turn, guides the search of the LNS towards a balance between minimizing delays for pending express and standard orders and minimizing vehicle routing effort in favor of future ones. To this end, we consider the CFA not only in the evaluation of newly generated route plans, but also directly in the (re)insertion heuristic of the LNS. Moreover, we adapt the CFA depending on the current workload by applying Bayesian Optimization to learn the parameterization for the expected demand volume on the one hand and to make dynamic adjustments depending on its realization on the other. We will demonstrate the advantages of our approach in comprehensive computational experiments that will also provide insights into the characteristics of the problem, particularly with respect to the implications of different order priorities.

Controlling the Transport Demand of the FIFA World Cup 2022 in Qatar

Justus Bonz[2], Ben Craze[3], Knut Haase[1], Martin Halligan[3], Matthes Koch[2], Tobias Vlćek[1]

[1]University of Hamburg, Germany; [2]Desior GmbH, Germany; [3]Infinitive Group Limited; tobias.vlcek@uni-hamburg.de

The 2022 FIFA World Cup in Qatar presented a unique logistical challenge, with up to four matches scheduled daily during the group stage. The close proximity of all locations put considerable strain on Doha's transportation infrastructure, affecting not only match attendees but also participants in parallel public events and festivals. Developing effective transportation plans that prioritize accessibility, sustainability, and safety required a nuanced understanding of the full spectrum of transportation demand.

This paper presents a newly developed, scalable, and comprehensive transportation demand simulation, that was coupled with a passenger counting and inflow control mechanism specifically designed for metro systems to approximate and manage transportation demand during large-scale events. The data-driven simulation is highly adaptable, encompassing several participant categories. The simulation framework draws on multiple large datasets to construct an accurate representation of the local population, event venues, transport hubs, accommodation options, and tourist attractions. Moreover, it considers variables such as the current load on transportation networks and event venues, as well as mode selection based on choice models.

In operation, our simulation successfully identified bottlenecks leading to delays and potential overloads across metro system segments, tourist hotspots, and event locations in preparation for the FIFA World Cup 2022 in Qatar. By using these insights, we developed targeted mitigation strategies and integrated them back into the simulation model to assess their impact. The results provided valuable guidance for policymakers and transportation planners, contributing to the overall safety and efficiency of the FIFA World Cup 2022.

FB 01: Semiplenary Martinez de Albeniz

Time: Friday, 06/Sept/2024: 9:45am - 10:45am · *Location:* Audimax
Session Chair: Alexander Hübner

Experience Analytics: an Operations Management View

Victor Martínez de Albéniz
IESE Business School, -; VAlbeniz@iese.edu

In service contexts, consumers usually travel a complex journey, structured as a sequence of interactions taking place in space and time. While these journeys have been conceptually described, their detailed dynamics are poorly understood. Only recently our community has started to use analytics to better identify what triggers certain behaviors. A process view can be extremely useful to track engagement over the journey and identify experience improvement opportunities. In this talk, we develop a Markov-Decision Process framework that integrates contextual physical and digital factors to model consumer behavior over journeys. We apply the model to distinct contexts such as museum visits, e-commerce navigation and city mobility.

FB 02: Semiplenary Osorio

Time: Friday, 06/Sept/2024: 9:45am - 10:45am · *Location:* Theresianum 0602
Session Chair: Marie Schmidt

Urban Transportation Simulation and Optimization: Large-Scale Network Modeling Meets Machine Learning

Carolina Osorio
HEC Montreal, Canada; carolina.osorio@hec.ca

This talk presents various physics-informed ML methods to search high-dimensional continuous spaces in a sample efficient way, with a focus on urban mobility applications. We present advances in three areas: (i) sample-efficient dimensionality reduction methods, (ii) sample-efficient simulation-based optimization algorithms, (i) variance reduction methods for gradient estimation. We present case studies based on various metropolitan areas. We identify and discuss research opportunities and challenges in the fields of simulation-based optimization and machine learning as applied to urban mobility problems.

FB 03: Semiplenary Papavasiliou

Time: Friday, 06/Sept/2024: 9:45am - 10:45am · *Location:* Theresianum 0606
Session Chair: Michael Breitner

Co-Optimization of Energy and Reserves in European Energy Markets

Anthony Papavasiliou

Technical University of Athens, Greece; papavasiliou@mail.ntua.gr

The ambitious goals for the integration of renewable energy sources in modern energy systems in order to combat climate change implies that the electricity supply chain becomes increasingly reliant on energy sources that are inherently and, to a large extent, unpredictable and out of human control. Reserves are backup resources that are needed in order to ensure that the electricity system can operate reliably despite the significant uncertainty caused by the massive integration of renewable resources. In addition to trading energy and access to networks, electricity markets worldwide are evolving in order to improve their processes for procuring reserves. Among numerous engineering challenges that this objective raises, one can single out formidable computational challenges for optimizing the allocation of conventional generation capacity between the provision of energy and reserves, and ensuring the delivery of these reserves over networks. The institutional challenges are also important, since the economics of price formation in electricity markets are deeply affected by how reserves are compensated and the conventional roles of network operators and power exchange operators become increasingly intertwined. This presentation presents a brief overview of the organization of electricity markets and discusses the aforementioned engineering and institutional challenges, the state of play in the European energy market, as well as the potential welfare benefits and institutional implications of exploiting operations research in order to achieve a smoother coordination of conventional resources as “dancing partners” to renewable energy resources.

FC 01: Gurobi Workshop

Time: Friday, 06/Sept/2024: 10:45am - 12:15pm · *Location:* Audimax
Session Chair: Robert Luce

Gurobi under the hood: Solving mixed-integer nonlinear optimization problems

Robert Luce

Gurobi Optimization, Germany; luce@gurobi.com

In recent years, the global solution of nonconvex and nonlinear mixed-integer optimization problems has received more and more attention from the commercial optimization software industry, shifting the boundary of what's considered solvable by generic optimization software, and what isn't. In this session we take a look under the hood of Gurobi, which uses a spatial branch-and-bound framework, specialized cutting planes, and heuristics for the solution of such problems. Further we will preview some upcoming nonlinear modeling capabilities of the upcoming Gurobi 12 release.

FC 02: Statistics and Machine Learning

Time: Friday, 06/Sept/2024: 10:45am - 12:15pm · *Location:* Theresianum 0602
Session Chair: Thomas Setzer

How to improve accessories sales forecasting of a medium-sized Swiss enterprise? A comparison between statistical methods and machine learning algorithms

Agneta Ramosaj[1], Nicolas Ramosaj[2], Marino Widmer[1]
[1]Université de Fribourg, Swizerland; [2]Haute école d'ingénierie et d'architecture de Fribourg, Switzerland; nicolas.ramosaj@hefr.ch

Forecasts accuracy is definitively a crucial topic for industrial companies. Indeed, its impacts are huge especially for finance and production departments. It can occur high costs for the company if the forecasts are not accurate, due to stock-outs or excesses of inventory, for example.

Therefore, the purpose of this study is to optimize accessories forecasting for a medium-sized Swiss enterprise. To do that, different forecasting techniques are tested, and a comparison is made between statistical methods and machine learning algorithms. The results have been adjusted thanks to the key account managers (KAM) expertise.

In this paper, a comparison between exponential smoothing, seasonal autoregressive integrated moving average (SARIMA), SARIMAX (SARIMA with exogenous regressors) and Machine Learning algorithms such as k-nearest neighbors (k-NN), LASSO regression, linear regression and even random forest is presented.

To compare these different methods, two measures of statistical dispersion are computed: mean absolute error (MAE) and root mean squared error (RMSE). These results have been standardized for a better comparison. It comes out that for our dataset SARIMAX (with the KAM's expertise as exogenous variable) gives better results that all the machine learning algorithms tested.

Ensembling Shrunk Weight Estimations in Forecast Combination

Veronika Wachslander, Thomas Setzer
Catholic University of Eichstätt-Ingolstadt, Germany; veronika.wachslander@ku.de

In most fields of business, accurate predictions are the basis for future planning, whereby combining predictions of different forecasters and/or forecasting models usually generates more accurate predictions than any individual forecaster or model alone.

While simply averaging forecasts using equal weights (EW) has proven to be a robust strategy in practice, an alternative approach applied in several recent papers is to learn so-called optimal weights (OW), that minimize the mean squared error (MSE) on past (training) data, and shrinking these weights towards EW. This strategy aims to learn structures from training data while mitigating overfitting and to avoid high prediction errors with novel forecasts.

However, estimating OW and shrinkage levels on training samples is still subject to uncertainty and can be highly unstable especially for smaller datasets and larger sets of forecasters. This turns out to be a key problem of such approaches, which usually do not systematically beat EW approaches in practical settings.

We introduce a new procedure to obtain more stable weighting schemes. The procedure learns OW on randomly drawn subsets of the training data and determines the optimal shrinkage towards EW on the respective omitted observations, resulting in varying shrunk weight vectors. Subsequently, these vectors are averaged so that the final weight each forecaster receives corresponds to the average (shrunk) optimal weight over all subsets and is asymptotically less extreme.

We evaluate the procedure on synthetic datasets, where it shows benefits compared to EW as well as OW approaches in terms of the out-of-sample MSE.

Machine-Learning-based Determination of Steinian Shrinkage Targets and Levels in Forecast Combination

Marco Fuchs, Thomas Setzer
Catholic University of Eichstätt-Ingolstadt, Germany; marco.fuchs@ku.de

While forecast combination generally improves forecast accuracy, a persisting research question is how to weight individual forecasters. One natural approach is to determine weights that minimize the mean squared error (MSE) on past error observations. Such weights can be computed from the past errors' sample covariance matrix, which is, however, an unstable estimator of the true covariance matrix, i.e., its variance is high unless there are many error samples – often not given in forecast situations. Hence, the estimation error associated with a sample covariance matrix often leads to overfitted weights and decreased accuracy of novel forecasts derived with such weights, quickly overwhelming potential accuracy gains due to learning weights. A remedy of this overfitting problem is the (Steinian) shrinkage of the sample covariance matrix to a rather inflexible target like the Identity matrix. This decreases the matrix's variance, albeit at the cost of introducing some bias. To apply Steinian shrinkage, two decisions must be made upfront. First, a suitable structure of the target needs to be set. Second, a shrinkage level must be determined that solves the bias—variance trade-off associated with the sample covariance and target matrix. While Steinian shrinkage exhibits promising outcomes in synthetic data experiments, we are not aware of data-driven approaches to select the target and determine the shrinkage level to be used in forecast combination.

In this paper, we propose machine learning-based tuning procedures for selecting targets and tuning shrinkage levels, where experimental analyses show promising results in terms of MSE reductions on unseen data.

FC 03: Data Analytics

Time: Friday, 06/Sept/2024: 10:45am - 12:15pm · *Location:* Theresianum 0606
Session Chair: Nataliya Kocheva

A comparative analysis of Machine Learning Algorithms based on Meta-heuristic algorithms in Feature Selection for Imbalanced Datasets

Nimet Yapıcı Pehlivan[1], Özlem Akarçay Pervin[2], Muhammed Nurullah Kutlu[1], Halil Osman Erbek[1]
[1]Selçuk University, Turkiye; [2]KTO Karatay University, Turkiye; nimet@selcuk.edu.tr

In real-world classification problems, imbalanced data is often encountered, characterized by significantly different sample sizes among various classes for binary class and multiple class cases. In this study, machine learning algorithms are implemented after feature selection on imbalanced data sets. At first, resampling methods such as SMOTE, and Tomek Link are carried out to solve the class imbalance problem. Second, metaheuristic algorithms, namely Particle Swarm Optimization (PSO), Artificial Bee Colony (ABC), etc. are used for feature selection to determine relevant features. Finally, machine learning algorithms like K-nearest neighbor, Support Vector Machine, Decision Tree, Random Forest, and Logistic Regression are performed to classification aim. Comparative analysis is realized via different performance metrics, accuracy, precision, recall, F-score, and Matthew correlation coefficient to evaluate the performances of the mentioned algorithms for imbalanced data sets.

Investigation of the impact of the time lag between training and test data sets on the accuracy of credit scoring models

Yanwen Dong, Noriki Ogura
Fukushima University, Japan; dong@sss.fukushima-u.ac.jp

As a large number of credit scoring models are built on a known set of data (training data) collected in the past or from other regions/domains, a prerequisite for applying these models to new instances is that the data of the new instances are comparable to the training data set. The comparability between the new instances and the training dataset also has a strong impact on the performance of credit scoring models. However, most studies have focused on the methods or algorithms for model construction, there is a lack of research on the impact of the time lag of the training data on the accuracy of credit scoring models. This study aims to fill this gap by investigating how the time lag between training and test data sets affects the accuracy of credit scoring models. We collected 13 years of financial data from Japanese regional banks for the period 2010-2022. We used each year's data for 2010-2021 as training data to construct credit scoring models using support vector machines (SVMs). We then applied the models to predict the credit scores of banks for the following years and confirmed the accuracy of the models. It was clarified that (1) the accuracy of the models decreased as the time lag between training and test data increased; (2) to achieve an accuracy of more than 90%, it is necessary to construct a credit scoring model using data from the previous year.

Beyond the Crystal Ball: Unveiling the Power of Causal and Generative AI for Strategic Foresight

Elena Fitkov-Norris, Nataliya Kocheva
Kingston University London, United Kingdom; n.e.kocheva@kingston.ac.uk

This paper explores how Artificial Intelligence (AI) can revolutionize strategic foresight enhancing its capabilities and guiding decision-makers through an ever-changing landscape to navigate uncertainties through the systematic exploration of potential futures. The unparalleled pace of change encountered today necessitates robust foresight capabilities to enable businesses to navigate uncertainty. Traditional foresight techniques, while valuable, do not consider the vast quantities of available data or attempt to model complex causal relationships.

The paper discusses the potential of emerging deep learning AI techniques, such as Causal and Generative AI, to enhance traditional foresight approaches by bridging the gap between quantitative and qualitative foresight methods, addressing challenges such as expert bias and data reliability. Causal AI harnesses the power of causal inference to model complex causal relationships and mitigate observational bias in data, equipping decision-makers with robust tools for scenario building. Generative AI and LLMs on the other hand, offer promising capabilities for automated horizon scanning and scenario generation, although the need for human oversight remains Ultimately, AI could empower individuals and organizations to not only anticipate the future but actively shape it.

FC 04: New Developments in Optimization under Uncertainty

Time: Friday, 06/Sept/2024: 10:45am - 12:15pm · *Location:* Wienandsbau 2999
Session Chair: EPAMINONDAS KYRIAKIDIS

Investing in the Supplier: Supply Improvement in a Newsvendor setup

Shivanee Pethe[1], Balram Avittathur[2]
[1]Masters' Union School of Business, Gurugram, India; [2]Indian Institute of Management Calcutta, Kolkata, India; balram@iimcal.ac.in

Firms such as Walmart, Fabindia and Asket have heavily invested in their supply chains to gain competitive advantage. These investments take the form of technological advancements that help the supplier firm create a more stable supply environment. To gain a deeper understanding of firm behavior and motivations, we explore this relationship from two perspectives namely a market-facing retailer exploring the idea of supplier improvement as a means for mitigating supply risk, and her supplier making a choice of whether to enter this contract.

We propose an investment that the retailer can make to stabilize her supply by improving the suppliers' capabilities. The buyer, or the retailer, approaches this as an investment problem, wherein she makes investment decisions to improve the quality of supply. We explore this question through mathematical constructs in a newsvendor retailer setting. Through modelling the choice of investment as a decision variable, we establish the benefits for a retailer to invest in her supplier and discuss various market scenarios where they may be beneficial. We simultaneously model the retailers' optimal order quantity to maximize the expected profit.

Our paper establishes a choice matrix which can be used by procurement managers and makes an important finding for cases of firms facing highly constrained or niche product supply. We find that in such cases where switching costs are high, she is still better off investing in the existing supplier, compared to if she does not make this investment.

Social Media Site Selection for Product promotion in Online Business- A Hesitant Fuzzy Linguistic Approach.

DevaHarshini Bhavisetty, Bindusree Velugula
Indian Institute of Technology Mandi, India; devaharshinibhavisetty@gmail.com

The proposed work introduces a new procedure based on Hesitant Fuzzy Sets, that enables a company to identify social media sites to promote its products that will have the maximum effect on the consumers. As the impact of social sites on the buyers is difficult to assess in single numeric or linguistic terms, the proposed work measures the influence of the buyers towards social sites, in Hesitant Fuzzy Linguistic Values (HFLVs). The linguistic term set with respect to buyers visit to the social sites are taken as: {Rare, Infrequent, Occasional, Regular, Frequent, Very Frequent}. Instagram, Facebook, WhatsApp, Telegram, YouTube, TikTok and Snapchat are the social sites considered in our work. The entropy, representing the uncertainties of buyers' impressions are suitably derived in the paper, after converting the linguistic terms in HFLVs into their numeric counterparts. The reverse of entropy is taken as the levels of self-confidence of the buyers in the social media sites. The proposed work picks the social media sites that provides the maximum buyers reach after accounting buyers' level of confidence and their frequency of visit. The methodology works under a budget constraints and modelled as a Binary Integer Programming problem.

Optimal control of a simple deterministic immigration-birth-death process through catastrophes

EPAMINONDAS KYRIAKIDIS
ATHENS UNIVERSITY OF ECONOMICS AND BUSINESS, Greece; ekyriak@aueb.gr

A pest population grows in a habitat according to a simple deterministic immigration-birth-death process. The rate of the cost caused by the pests is increasing with respect to the population size. The pest population may be controlled by some action that introduces total catastrophes. The length of time until the occurrence of a catastrophe is exponentially distributed. We restrict our attention to the class P of control-limit policies that take controlling action if and only if the pest population size exceeds a critical number. The control-limit policy which minimizes the expected long-run average cost per unit time within the class P is found. The optimal control-limit policy is compared with the optimal control-limit policy that we obtain in the case in which the pest population grows according to the simple stochastic immigration-birth-death process. Numerical results are provided to illustrate the theoretical results.

FC 06: Routing

Time: Friday, 06/Sept/2024: 10:45am - 12:15pm · *Location:* Wirtschaftswissenschaften Z534
Session Chair: Julia Erdmann

A Branch-and-Cut based Matheuristic for the Vehicle Routing Problem with Time Windows

Lelisa Kebena Bijiga, Steffen Rebennack, John Alasdair Warwicker
Karlsruhe Institute of Technology, Germany; lelisa.bijiga@kit.edu

Advancements in computer hardware technology and commercial-purpose software have paved the way for leveraging branch-and-cut 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 remains a challenge. In this study, we explore the potential of combining branch-and-cut techniques with constrained k-means clustering.

Our work focuses on a Matheuristic approach that integrates branch-and-cut methods with constrained k-means clustering. We achieve this by decomposing the original VRP into subproblems using constrained k-means clustering, where the clustering assignment subproblem is reformulated as a minimum-cost flow linear network optimisation problem.

Our methodology begins by decomposing the customers into geographical-based clusters, thereby imposing the manageable size for the subproblems and facilitating efficient application of branch-and-cut techniques. Subsequently, these subproblems are solved iteratively to derive a comprehensive solution. To improve the final solution obtained, we conduct cross-validation through rigorous back testing. We demonstrate the effectiveness of our approach on known benchmark instances of VRPs with time windows and compare it with state-of-the-art solutions. Our result shows that the approach achieves comparable or better performance for up to 400 customers.

Branching strategies for solving routing problems to 3D design in manufacturing

Maialen Murua[1], Roberto Santana[2]
[1]TECNALIA, Basque Research & Technology Alliance (BRTA); [2]University of the Basque Country (UPV/EHU);
maialen.murua@tecnalia.com

Digital 3D objects find extensive application across various industries, notably in manufacturing. Within the realm of generating 3D computer images, cubic graphs hold particular significance despite posing challenges in hardware implementation. A notable approach to alleviate this challenge involves reducing triangles into a single strip, which notably eases hardware processing. Achieving such a single strip alignment corresponds to solving the Hamiltonian cycle problem (HCP) in the dual graph. Notably, branch-and-bound methodologies are essential in tackling constraint satisfaction problems like the HCP. Recent studies underscore the efficacy of adaptive branching strategies over fixed schedules. This research introduces a novel branching strategy focused on maximizing fixed arcs within the Hamiltonian cycle, comparing its effectiveness against other established methods in the field.

Practical Student Project: Routing of swap bodies between parcel sorting centers

Johannes Quast, Alexander Helber, Marco Lübbecke
RWTH Aachen University, Germany; johannesquast@outlook.de

As part of a practical student project at RWTH Aachen University, we looked at the problem of how large parcel service providers manage the huge volumes of parcels that have to be transported between different sorting centers every day.

When transporting the swap bodies that contain the parcels, a fine balance must be struck between low transport costs and timely delivery to the destination. Furthermore, the sorting centers are subject to a limited throughput, i.e., the number of parcels that can be processed per hour, which must be respected.

As part of this project, the key question of how to optimize the routing of transport containers between locations while ensuring that many shipments can be delivered the next day had to be answered. Because the project has only just started at the beginning of the semester, we are very excited to find out which of the various models and algorithmic approaches will result in the best outcome possible, and we are looking forward to sharing our findings with you!

The Impact of Integrating Resource Collection into Location-Routing Problems

Julia Erdmann, Tristan Becker
TU Dresden, Germany; julia.erdmann@tu-dresden.de

The proximity to resource and customer locations is among the most important criteria in site selection for manufacturing companies. For many applications, e.g., in the area of circular economy, companies have to bear the responsibility of collecting resources. In such scenarios, their operational planning involves the selection of resource markets as well as the generation of resource collection and customer delivery routes. While the Location-Routing Problem (LRP) integrates the facility location and customer delivery routing, there is a lack of integrated approaches that additionally take resource collection routes into account. Recognizing this need for a comprehensive approach, we introduce a novel integer mathematical programming model, the Location-Routing Problem with Resource Collection and Customer Delivery (LRP-RCCD). By integrating the LRP with the Multi-Depot Traveling Purchaser Problem (MDTPP), the LRP-RCCD minimizes operational and transportation costs while meeting customer demands. This unified framework allows for the simultaneous optimization of location decisions, resource selection, resource collection routes, and customer delivery routes. We consider multiple resource types, each of which is available from multiple markets with heterogeneous prices, making efficient resource selection and collection routing crucial. To investigate the value of an integrated modeling of resource collection and customer delivery routes, we conduct computational experiments using exemplary test instances. We compare the results of considering only customer routes with simplified direct resource collection in site selection with those obtained using our integrated LRP-RCCD formulation.

FC 09: Pricing

Time: Friday, 06/Sept/2024: 10:45am - 12:15pm · *Location:* Wirtschaftswissenschaften Z532
Session Chair: Yifan Hu

Simple and Effective: A Deterministic Auction with Support Information

Rishikesh Parma, Cagil Kocyigit, Benny Mantin
University of Luxembourg, Luxembourg; rishikesh.parma@uni.lu

We study an auction design problem, where a seller aims to sell an item to multiple bidders. Bidders' willingness to pay (values) are independent random variables, and the seller only knows an upper bound on these values, lacking distribution knowledge. The objective is to devise a deterministic mechanism effective across various plausible distributions. We propose a second price auction with a reserve price set to half of the upper bound. Despite no deterministic mechanism can achieve a positive fraction of the maximum achievable expected revenue across all distributions, we define a distribution class G, which is extensive and contains several distributions of practical importance, and we demonstrate that our mechanism achieves at least 1/4 (1/2 under i.i.d. values) of the maximum expected revenue for distributions within G. We conduct numerical experiments to evaluate our mechanism's performance beyond G, under randomly generated distributions, demonstrating its superior performance in approximately 95% of the generated instances compared to benchmark mechanisms from the literature. We illustrate numerically that our mechanism exhibits greater robustness against different correlations than the benchmarks when considering two non-independent bidders. We consider the scenario where the estimated upper bound is subject to errors and show that appropriately lowering the reserve price based on estimation confidence ensures a constant positive fraction of the maximum expected revenue across G. Traditional auction design strategies often propose randomized mechanisms that lack interpretability, implementability and transparency, causing trust issues among bidders. Instead our mechanism is simple, requires minimal information, and is effective in practical scenarios.

Learning Commissions and Subscription Fees under Uncertainty in Two-Sided Marketplaces

Christina Johanna Liepold[1], Maximilian Schiffer[1,2]
[1]School of Management, Technical University of Munich; [2]Munich Data Science Institute, Technical University of Munich; christina.liepold@tum.de

Two-sided marketplaces are online platforms that facilitate exchanges between suppliers and buyers as they reduce search costs, for example, in the context of vacation rentals, freelancing, or salon bookings. Marketplace operators do not offer this service for free but charge marketplace fees, which are the basis for revenue generation and the marketplace's long-term economic success. There are two main types of marketplace fees, which can also be adapted jointly: commissions, where the operator keeps a percentage of the total transaction amount, and subscription fees, flat fees paid by all users for accessing the marketplace.

Existing research approaches analytically evaluate optimal marketplace fees, focusing on deterministic settings. These approaches discuss how to optimally fix commissions and subscription fees a priori to maximize marketplace operator revenue or overall marketplace welfare. In practice, however, marketplace operators face multiple uncertainties regarding the market setup that complicate the fee-setting procedure, such as suppliers' and buyers' stochastic arrivals, pricing expectations, and maximum waiting times. To address this gap, we propose an adaptive design of marketplace fees based on deep reinforcement learning (DRL), enhancing the operator's ability to navigate inherent market uncertainties. As the agent, the platform learns forward-looking fee-setting policies for each transaction and each time period in an uncertain market environment under revenue maximization for all marketplace users. Exploring the intersection of DRL and the platform economy, this approach allows for non-myopic fee-setting in marketplaces by considering the impact of these fees on the overall welfare of all marketplace participants and the operator's revenue.

Stochastic optimization of hybrid product configurations

Alexander Baumeister[1], Holger Hermanns[1], Ralf Jung[2]
[1]Saarland University, Germany; [2]ETH Zurich, Switzerland; a.baumeister@con.uni-saarland.de

Innovative revenue models, e.g. as hybrid products through jointly selling a tangible asset with services to be provided later, complicate operational performance management considerably, since capacity requirements in subsequent periods are predetermined by guaranteed follow-up services. The type of the corresponding service level agreement and the conditions of the service call determine how services have to be provided, at least partly beyond the company's own control. As a consequence, the customer's stochastic call-off behaviour must be modelled for contractual design, supply planning and service management. Although there is already extensive literature that deals, e.g., with bundle pricing, congestion pricing or dynamic pricing of such hybrid products, there is no consideration of the risk of later capacity bottlenecks from the current scheduling of uncertain later service calls from new business. This effect must be taken into account when structuring the contractual conditions, esp. pricing, in order to enable optimal production and sales planning under risk. The paper develops a model for this purpose, which is investigated by simulation using a case study. In this evaluation, the sample average approximation and the scenario approach will be contrasted.

The impact of asymmetric WTP distributions on the pricing of bundles containing flexible products

Ralf Gössinger, Jacqueline Wand
University of Dortmund, Germany; jacqueline.wand@tu-dortmund.de

A flexible resource utilization can be beneficial for a multi-product vendor in times of increased uncertainty. One possibility is to offer flexible bundles, i.e. bundles that contain flexible products. While price bundling makes it possible to achieve the capacity utilization with the highest expected profit at the time of purchase, flexible products provide opportunities to manage demand and resource uncertainties in the time between purchase and delivery. However, both have a significant impact on customers' purchasing behavior. An empirical study was conducted to collect data on customers' individual WTP range for flexible bundles. It turned out that customers perceive greater performance uncertainty the more flexible the bundles are. As a result, the individual WTP range becomes narrower and has a lower mean value. Since this effect is moderated by the customer's purchasing power and risk attitude, different customer segments can be formed. However, the segment-related aggregation of individual WTP ranges results in asymmetric distributions, which are difficult to handle analytically and numerically. Against this background, we propose a way of how to incorporate asymmetric WTP distributions into a bundle pricing model that can be solved by standard optimization software. A numerical study provides insights into profit, sales quantities and prices depending on the characteristics

of both customer segments and capacity. Furthermore, we determine the impact of incorrect assumptions about segment-related WTP distributions on the advantageousness of pricing.

FC 10: Patient Operations

Time: Friday, 06/Sept/2024: 10:45am - 12:15pm · *Location:* Wirtschaftswissenschaften 0514
Session Chair: Stefanie Ebel

Structural insights about roommate suitability in the patient-to-room assignment problem

Tabea Brandt, Christina Büsing, Felix Engelhardt

RWTH Aachen University, Germany; brandt@combi.rwth-aachen.de

Assigning patients to rooms is a fundamental task in hospitals and, especially, within wards. This so-called patient-to-room assignment problem (PRA) has gained more and more attention in the last few years and many heuristics have been proposed with a large variety of different practical constraints reflecting different settings in hospitals. Classical objectives are avoiding patient transfers between rooms, respecting single-room requests, or choosing patients of similar age as roommates.

Apart from age difference, there are many other potential criteria for determining the roommate suitability. In this talk, we take a look at the mathematical structure of different suitability criteria and compare different strategies for integrating them into algorithms for PRA.

A Granular Approach to Optimal and Fair Patient Placement in Hospital Emergency Departments

Maureen Canellas[1], Dessislava Pachamanova[2], Georgia Perakis[3], Omar Skali Lami[4], Asterios Tsiourvas[3]

[1]University of Massachusetts Chan Medical School, Worcester, MA, USA; [2]Babson College, Wellesley, MA, USA; [3]Massachusetts Institute of Technology, Cambridge, MA, USA; [4]McKinsey & Co, USA; dpachamanova@babson.edu

This work, in collaboration with a large hospital system in Massachusetts, USA, tackles the patient prioritization and placement aspects of emergency department operations with the goal of improving throughput and wait times in an equitable way. We present a novel predictive-prescriptive framework, operationalize it through an interpretable metamodel, and demonstrate increased fairness in patient prioritization.

The value of flexibility in integrated surgery and staff scheduling on a daily planning level applying a column generation heuristic

Stefanie Ebel, Jens O. Brunner

Universität Augsburg, Germany; stefanie.ebel@uni-a.de

Two of the most important, expensive and scarce resources in hospitals are physicians and operating rooms. Therefore, effective and efficient scheduling of these resources is among the most relevant planning tasks within hospitals. The decisions to be made on the daily planning level regard the sequencing of patients' surgeries and the assignment of appropriate staff to surgeries. Since there are several interdependencies between surgery schedules and physician rosters, it is a meaningful approach to consider both planning problems within one integrated optimization problem. We provide MIP models for a column generation algorithm that solves both scheduling problems within one simultaneous solution approach to create schedules for surgeries as well as for operating room staff. We use test data based on a real-world dataset to provide meaningful insights. The algorithm leads to optimal solutions in more than 75% of all test cases and solves the problem efficiently within a desirable amount of time. We further evaluate our algorithm with respect to different aspects of flexibility in the context of surgery and staff scheduling and generate key insights about their interdependencies.

FC 11: Supply Chain Coordination

Time: Friday, 06/Sept/2024: 10:45am - 12:15pm · *Location:* Theresianum 2609
Session Chair: Eunji Lee

Do consumers make optimal repair vs. replacement decisions?

Fachbach Ines[1], Reimann Marc[1], Souza Gilvan[2], Guido Voigt[3]

[1]Universtiät Graz; [2]University of Tennesse; [3]Universität Hamburg; guido.voigt@uni-hamburg.de

Ensuring that products are repairable and durable have become increasingly important topics in legislation, with the objective of reducing waste and promoting a circular economy. However, to assess the effectiveness of such measures and laws on repair demand, it is crucial to first understand how individuals make repair versus replacement decisions and to further identify to what extent increased product repairability and durability can impact those decisions. To that end, we conducted an incentivized laboratory experiment where participants were asked to make sequential repair versus replacement decisions given repair and replacement costs, product age, and the product's failure probability. To determine the effectiveness of the participants' decisions, we compared them to the optimal (expected discounted-profit maximizing) repair versus replacement decision based on a Markov decision process model from the machine replacement literature. We find that about 70% of all decisions in the experiment are optimal and only a minority of subjects never choose to repair, suggesting that strictly from a financial standpoint, individuals are often aware of the optimal decision, which could mean to repair more often. To include the perspective of a product's repairability and durability, one treatment in the experiment considered a product with lower repair costs (more repairable), and another treatment included a product with a lower growth rate of its failure probability (more durable).

How power structure and markup schemes impact supply chain channel efficiency under price-dependent stochastic demand

Eunji Lee[1], Stefan Minner[2]

[1]University of Mannheim, Germany; [2]Technical University of Munich, Germany; eunji.lee@uni-mannheim.de

Although considerable attention has been separately given to factors such as power structures, price-dependent demand, and markup pricing schemes, there has been limited exploration of the combined effects of these factors on supply chain efficiency and the leader's advantage. We propose a game theoretic model in which a manufacturer sells a single product to a newsvendor retailer who sets both optimal order quantity and selling price under uncertain price-dependent demand. Furthermore, we examine a supply network wherein a single retailer fulfills orders using a global manufacturer for regular orders and a local manufacturer to clear any shortages. Through numerical analysis, we show that the retailer always prefers to charge a percentage markup. In a two-player game, channel efficiency is higher when the retailer is the leader under linear demand; however, under iso-elastic demand, the manufacturer being a leader brings a higher channel efficiency. When a local manufacturer is involved as a second manufacturer, channel efficiency is higher when the retailer remains a follower, as this induces more fierce wholesale price competition between the two manufacturers. Additionally, when demand uncertainty is high in the two-player game with linear demand, the retailer as a follower can achieve higher profits, whilst high uncertainty under iso-elastic demand decreases both players' profits. Moreover, it becomes advantageous for the retailer to have a local manufacturer as demand uncertainty increases, even when the local manufacturer announces the wholesale price first.

Quality Cost Information Asymmetry in Mobile Applications Supply Chain and a Two Part Tariff Contract

Mohd Kamran Rais Khan, Avijit Khanra

Indian Institute of Technology Kanpur, India; kamran@iitk.ac.in

Mobile Applications Supply Chain (MASC) consists of an app developer and a platform owner, where app developer is considered to be closer to customers and is responsible for research and development of the app. The platform owner provides a platform to sell the app and receives a part of the revenue. App development industry has various types of developers with respect to their experience. More experienced developers will incur less cost for the same level of quality or less experienced guys will deliver lower quality for the same cost. Since the quality level of the app and its cost is decided by the developer, it can be private to him only. The developer has the incentive to falsify this information and try to get larger percentage of revenue while delivering lower quality levels. The profit of the platform owner will go down in this situation. We propose a menu of contracts for app developer to reveal his cost information truthfully by incentivizing him. Moreover, we have proposed a two part tariff contract for the MASC. The contract is such that the app developer will get the revenue share only after the app demand crosses a certain level of demand, till then he gets a fixed amount. In comparison to revenue sharing contract it performs better.

Nucleolus-type allocations in hierarchies when cooperation is costly

Tamás Solymosi

Corvinus University of Budapest, Hungary; tamas.solymosi@uni-corvinus.hu

We consider a multi-agent decision situation when cooperation is possible, but constrained by a hierarchy of the agents. Moreover, having access to a "crucial resource" is necessary for being able to materialize the potential profit-making capabilities of the agents. Making this resource, capable of serving any subgroup of the agents, available has a fixed investment cost. Utilization of the resource is hierarchical, represented by a rooted tree graph. The root represents the resource, each other node of the tree represents one of the agents with a given profit-making potential that can only materialize if all agents on the path to the root are also participating.

We study fair and stable allocations in such ”hierarchical joint venture” situations determined by solutions of associated cooperative games. We define the value of a coalition of agents as the sum of the individual potential profits of those members who are connected to the root via other members within the coalition minus the fixed (independent of the coalition to be served) investment cost of the "crucial resource". We consider the standard, the per-capita, and the disruption nucleoli, and investigate whether and how these nucleolus-type allocations can be computed directly from the parameters modeling the ”hierarchical joint venture” situation, so there is no need to explicitly generate the exponential-size associated cooperative game and compute its nucleoli with general-purpose algorithms.

FC 12: Approximations for MCDM

Time: Friday, 06/Sept/2024: 10:45am - 12:15pm · *Location:* Theresianum 2601
Session Chair: Levin Nemesch

Dimension reduction for the approximation of high-dimensional nondominated sets

Volker Maag, Ina Lammel

Fraunhofer-Institut für Techno- und Wirtschaftsmathematik, Germany; ina.lammel@itwm.fraunhofer.de

Many real-world optimization problems depend on several criteria. The computational effort of approximating the nondominated set of these multiobjective optimization problems increases quickly with the number of objectives. For a large number of objectives, computing a good approximation of the nondominated set may exceed the available computation budget.

In many practical multiobjective optimization problems, we observe a high correlation between some of the objectives. To compute approximations of these high-dimensional nondominated sets, we incorporate dimension reduction techniques into the approximation process. We first analyze the problem to identify strongly-correlated directions of the nondominated set and reduce the objective space dimension accordingly. After computing an approximation in the lower-dimensional space, we project the approximation back to the original full-dimensional space.

We relate the approximation of the nondominated set constructed by this algorithm to the approximation of the full-dimensional set and develop criteria under which the approximation in lower-dimensional space still yields a good approximation when projected back to the full-dimensional space.

Finally, we demonstrate the usefulness of the method on examples from different fields of application.

Exploring the Parallels – From Multi-objective Convex Approximation to Parametric Approximation

Levin Nemesch[1], Stefan Ruzika[1], Clemens Thielen[2], Alina Wittmann[2]

[1]RPTU, Germany; [2]TUM, Germany; alina.wittmann@tum.de

In linear parametric programming problems (PPP), several objective functions are combined into a single objective function by forming a linear combination. An optimal solution should then be found for every possible combination of coefficients (parameters) of the linear combination from a given set. Parametric programming is related to numerous other areas such as multi-objective optimization and sensitivity analysis. It appears in a wide range of application areas ranging from waste management and fleet planning to model-predictive control and process synthesis under uncertainty.

Solving a PPP requires a set of solutions that contains an optimal solution for each possible combination of parameter values. It is well-known that, for many important discrete optimization problems, the number of solutions needed is exponential in the input size of the problem. Consequently, this motivates the development of approximation algorithms.

Considering the limited literature available, we use a central tool to develop approximation algorithms for PPP. We describe the connection between convex approximation in multi-objective optimization and approximation of PPPs with positive parameters. Through this connection, we show how to transfer existing results from multi-objective optimization to the parametric setting. The potential of this approach becomes apparent when cardinality bounds are taken into consideration. Using the minimum cut problem as an example, we use known results from the parametric programming literature and extend them with results from multi-objective optimization.

Inner Approximation Methods for α-Approximation in Parametric and Multi-objective Optimization

Levin Nemesch[1], Stefan Ruzika[1], Clemens Thielen[2], Alina Wittmann[2]

[1]RPTU, Germany; [2]TUM, Germany; l.nemesch@math.rptu.de

The fields of multi-objective optimization and parametric optimization are closely related. This relation can be used to devise approximation methods. Any so-called α-convex approximation set for a multi-objective optimization problem (MOP) is also an α-approximation set for the corresponding parametric optimization problem. In this talk, we present an algorithm for multi-objective convex approximation, and then outline how to extend it to be a more general algorithm for parametric optimization.

Our multi-objective α-convex approximation algorithm builds upon so-called inner approximation methods, established approaches to find the non-dominated extreme points of a MOP. We show how a generic inner approximation algorithm can be adapted into a convex approximation algorithm through rather minor adjustments. The resulting algorithm avoids a classic shortcoming that affects most other multi-objective approximation algorithms. There, a huge grid in objective space is constructed a priori, and for a significant number of cells in this grid, an operation is required. In contrast, our algorithm is the first of its kind to work completely grid-agnostic.

Building upon this algorithm, we outline how to adapt it for parametric optimization. Our parametric approximation algorithm is the first such algorithm that can work on arbitrary parameter intervals. It can be a valuable addition to the toolboxes of researchers and practitioners alike.

FC 13: Algorithmic Advances

Time: Friday, 06/Sept/2024: 10:45am - 12:15pm · *Location:* Theresianum 2605
Session Chair: Suresh Bolusani

Component Bound Branching in a Branch-and-Price Framework

Til Valentin Mohr

RWTH Aachen University, Germany; til.mohr@rwth-aachen.de

This master thesis integrates the component bound branching rule, proposed by Vanderbeck et al., into the branch-price-and-cut solver GCG. This rule, similarly to Vanderbeck's generic branching scheme, exclusively operates within the Dantzig-Wolfe reformulated problem, where branching decisions generally have no corresponding actions in the original formulation. The current GCG framework requires modifications for such branching rules, especially within the pricing loop, as seen in Vanderbeck's method implementation. These rules also fail to utilize enhancements like dual value stabilization.

A significant contribution of this thesis is the enhancement of the GCG architecture to facilitate the seamless integration of new branching rules that operate solely on the reformulated problem. This allows these rules to benefit from current and future improvements in the branch-price-and-cut framework, including dual value stabilization, without necessitating alterations to the branching rule itself.

The thesis proposes an interface to manage constraints in the master problem that lack counterparts in the original formulation. These constraints require specific modifications to the pricing problems to ensure their validity in the master. The 'generic mastercut' interface, tightly integrated into the GCG solver, spans the pricing loop, column generation, and dual value stabilization. Enhancements to the existing branching rule interface complement this integration, enabling effective utilization of the generic mastercuts.

Finally, the component bound branching rule will be implemented using this new interface and evaluated on a set of benchmark instances. Its performance will be benchmarked against the existing Vanderbeck branching rule, offering a practical comparison of both approaches.

The Relax-and-Cut Framework in the SCIP Optimization Solver

Suresh Bolusani[1], Gioni Mexi[1], Mathieu Besançon[2], Mark Turner[1]

[1]Zuse Institute Berlin (ZIB), Germany; [2]University Grenoble Alpes, Inria, France; bolusani@zib.de

The existing literature on the relax-and-cut framework discusses its usage to generate lower-ranked cuts for mixed-integer optimization problems. Such lower-ranked cuts are essential to avoid numerical troubles of the solving process (e.g., a branch-and-cut algorithm) involving cuts such as the Gomory mixed-integer cuts. However, this literature focuses mainly on closing the root node gap in a branch-and-cut tree to solve these problems and does not dive deep into solving these problems to optimality faster. The relax-and-cut framework in the SCIP optimization solver addresses this gap in the literature by employing various novel techniques and implementations.

This talk will discuss the relax-and-cut framework in SCIP, an open-source optimization solver for solving mixed-integer optimization problems via a branch-cut-and-price implementation. Specifically, it will highlight how this framework can be used for dual and primal bound improvements while solving an optimization problem. Computational experiments on the MIPLIB 2017 benchmark dataset show an improved solving time and the number of nodes, especially for harder instances.

FC 14: Optimization in Sports and Work-Rest

Time: Friday, 06/Sept/2024: 10:45am - 12:15pm · *Location:* Theresianum 2607
Session Chair: Thomas A. Weber

Arena Seat Planning under Distancing Rules

Usama Jalal Dkaidik, Matthes Koch
Universität Hamburg, Germany; usamadkaidik@gmail.com

The COVID-19 pandemic has significantly impacted the organization and attendance of live events for several years, particularly in confined spaces such as arenas. To address these challenges, we developed and analyzed models for optimal arena seating configurations that adhere to social distancing protocols. Our primary focus is on maximizing seating capacity while ensuring safety through appropriate spacing between attendees from different households.

Our approach involves formulating a 2D knapsack problem-inspired model, where seats are allocated to groups of varying sizes, considering both horizontal and vertical distancing constraints. This model enables the generation of seating plans that optimize the number of attendees and comply with health regulations. We explored two distinct strategies: operational/tactical and strategic, each tailored to different event types and priorities, such as maximizing overall attendance or accommodating VIP and sponsor groups.

Our collaboration with a German football club demonstrates the effectiveness of our models. By applying our approach under various scenarios and constraints, we demonstrated their adaptability and potential for substantial gains in seating capacity and event revenue compared to traditional methods. Our framework offers a robust decision-making tool that can be easily extended to other domains requiring similar social distancing protocols.

Optimal Work-Rest Cycles

Thomas A. Weber
EPFL, Switzerland; thomas.weber@epfl.ch

For a system whose state declines when ’active’ and increases otherwise, we determine optimal work-rest cycles. The optimal switching policy maximizes the average cycle benefit, where the benefit at any given time is proportional to the system state during an active period and zero otherwise. Any given lower bound for the length of a rest period determines a unique limit cycle, where the state converges, irrespective of its initial value. The average benefit becomes maximal when the length of the resting period converges to zero and the system reaches a steady state of ’flow’ with a nontrivial work-rest split. For that case, we provide a relatively robust parameter estimate, valid in the absence of any knowledge about the system’s time constants. The results apply to regenerative systems determining the optimal split between uptime and downtime for maximum user benefit.

FC 16: Continuous and Pharmaceutical Production

Time: Friday, 06/Sept/2024: 10:45am - 12:15pm · *Location:* Wirtschaftswissenschaften 0540
Session Chair: Nico Florian Gärtner

Circular economy application in pharmaceutical supply chains in the UK: a holistic evolutionary game approach

Nazanin Nami, Grigory Pishchulov, Joao Quariguasi frota net
University of Manchester, United Kingdom; nazanin.nami@postgrad.manchester.ac.uk

The environmental hazards of improperly managed waste have gained universal recognition among scholars and stakeholders. These hazards are especially critical in the pharmaceutical sector since leftover medications contain active chemicals that threaten the environment and human health. Nonetheless, implementation of adequate measures to ensure proper collection and treatment of pharmaceutical leftovers remains insufficient, and tons of unwanted medications are discarded in landfills and wastewater annually. Such outcomes are due to lack of coordination between the parties involved and poor incentive systems in place. To address this issue, we study coordination in pharmaceutical reverse supply chains and government incentive strategies. We employ the evolutionary game methodology to evaluate strategic behaviour of pharmacies and a waste recycler under different incentive plans. We are focusing on both reward- and awareness-driven customer segments to boost the return volume of unwanted medications. Moreover, supply chain coordination is investigated as a tool to enhance the economic viability of the system. We compare the incentive plans based on return volume, participation rate, budget spend, and implementation time, to recommend the most effective plan. An extensive numerical study provides insights into the performance of the incentive plans in different conditions. The results reveal that a plan that provides proper incentives to pharmacies for targeting both, reward- and awareness-driven customers, coupled with contract-based coordination, outperforms other plans, and does not necessarily require a budget allocation. Our study is motivated by the UK's National Health System but it is generalisable to pharmaceutical reverse supply chains in other countries as well.

Label printing with color constraints

Herbert Meyr, Julian Maihöfer
University of Hohenheim, Germany; h.meyr@uni-hohenheim.de

A real world problem from the consumer goods' label printing industry is considered which differs from the well-known Label Printing or Cover Printing Problems by additionally respecting color constraints. Several sorts of similar labels have to printed on parallel lanes of a quasi-endless roll of paper using different printing plates. The various sorts need different colors, which have to be installed in the printer's limited number of color slots. Both changing the colors and designing the plates incur fixed costs. Because all lanes have to be printed simultaneously and because demands of the sorts are heterogeneous, waste may occur which causes variable costs per unnecessarily printed label. It has to be decided how many and which printing plates to design, how long to run each plate and how to change the colors in the slots so that demand is fulfilled while total costs are minimized. Two linear mixed integer programming (MIP) formulations and several decomposition heuristics are suggested to model and solve this problem. Various numerical experiments using practically relevant data test both MIP formulations, gain structural insights into the problem's and the MIP formulations' characteristics and compare the different heuristics.

Enhancing integrated planning and scheduling of continuous casting and hot rolling using steel grade upgradeability

Nico Gärtner, Thomas Volling
Technical University Berlin, Germany; n.gaertner@tu-berlin.de

The continuous casting (CC) and hot rolling (HR) stages are among the most energy-intensive in steel production. This is mainly due to the fact that the planning and scheduling of both processes are largely decoupled from each other. As a result, the majority of slabs cool down significantly after CC, while waiting for further processing. Just before HR these slabs must be reheated to the required process temperature of approximately 1200°C. Integrated planning of both processes can help minimize waiting times and boost energy efficiency by increasing the proportion of hot charged slabs. The challenge lies in reconciling the various incompatible process restrictions of CC and HR. To address this issue, we propose an aggregated mixed-integer linear model for the integrated planning problem. Steel grade upgrades are used to provide additional flexibility in mitigating the effects of incompatible process restrictions. Based on a numerical case study, we examine three upgrading strategies, assessing their impact on productivity and energy efficiency. The findings demonstrate the potential of upgradeability in the context of integrated planning.

FC 17: Transportation Scheduling in Supply Chains

Time: Friday, 06/Sept/2024: 10:45am - 12:15pm · *Location:* Wirtschaftswissenschaften 0544
Session Chair: Marina Mardanova

A two-stage procedure for determining optimal delivery profiles in the tactical planning horizon.

Marina Mardanova

Fraunhofer IML, Germany; marina.mardanova@iml.fraunhofer.de

To ensure a predictable and transparent delivery planning, companies define delivery profiles that provide a fixed delivery frequency for each supplier and facilitate planning for partners in the supply chain. The final order quan-tities are consolidated within a fixed timeframe before each delivery date, al-lowing for realization of bundling effects. Ideally, an integrated approach should be taken, where the transportation costs of each supplier are mini-mized, and the delivery days among all suppliers are coordinated to prevent overload at the receiving end. This paper presents a two-stage approach for such an integrated determination of delivery days. In the first stage, an ex-tension of a lot-sizing model is performed to incorporate fixed delivery fre-quencies. The first-stage model calculates cost-optimized supplier-specific delivery frequencies. In the second stage, a model is defined to orchestrate the delivery dates of all suppliers within their optimal delivery frequencies, ensuring a balanced delivery at the receiving end. Both models are solved us-ing an open-source solver. The optimal delivery days of the proposed ap-proach are evaluated compared to the currently implemented delivery pro-files through an industry case study. The results are analyzed in terms of monetary savings and optimization time to demonstrate the effectiveness of our approach.

A Multi-Objective Optimization for Efficient Pickup and Delivery Problems: Addressing Alternative Locations and Time Windows

Chinchet Boonmalert, Aua-aree Boonperm, Wutiphol Sintunavarat

Department of Mathematics and Statistics, Faculty of Science and Technology, Thammasat University, Thailand; chinchet.b@gmail.com

The realm of logistics optimization is constantly evolving to reflect the intricacies of real-world scenarios. This research delves into the progression from the traditional Vehicle Routing Problem (VRP), focused solely on delivery routes, to the Pickup and Delivery Problem (PDP). The PDP extends this framework by incorporating both pickup and delivery tasks, mirroring the complexities of modern logistics, particularly in sectors like e-commerce where both collecting and delivering goods are crucial steps in the fulfillment process. PDPs hold immense significance for numerous industries. Efficient management of pick-up and delivery operations directly impacts cost reduction and customer satisfaction. This study takes a deep dive into a multi-objective optimization approach for PDPs, acknowledging the added complexities introduced by factors like alternative pick-up locations and time window constraints. Unlike traditional approaches, our methodology aims to optimize for multiple objectives simultaneously. By minimizing both delivery lateness and overall transportation costs, we strive to create a more efficient and adaptable logistics framework. Through this investigation, we aim to develop innovative strategies that enhance the effectiveness of logistics operations. Our findings hold the potential to contribute to advancements in supply chain management and transportation optimization, ultimately leading to a more streamlined and cost-effective logistics landscape.

FC 18: Renewable Operations

Time: Friday, 06/Sept/2024: 10:45am - 12:15pm · *Location:* Theresianum 0601
Session Chair: Yvonne Blum

MV connection requests in Portugal mainland - the challenge of managing operations between regulatory obligations and sector expectations

Fabrice Gonçalves, José Cardoso, Ana Pereira, Luis Moreira, Paulo Vitorino
E-REDES, Portugal; fabrice.goncalves@e-redes.pt

E-redes, S.A. is the main Distribution System Operator (DSO) for high (HV), medium (MV), and low voltage (LV) in Portugal mainland. In Portugal, energy distribution is a regulated activity with regulated revenues, thereby managing OPEX is particularly relevant for E-redes' operations. One of E-redes main responsibilities is to ensure customer connection to the distribution network, according with regulated prices and response time. This article aims to describe some actions taken in operations management related with MV customers connection process, focusing on the following aspects:

- Meeting deadlines defined by the regulator for this activity (avoiding penalties)

- Minimizing process times to meet MV customers' expectations and thus contribute for boosting country's economic activity (industry, services, etc.)

- Maximizing operations efficiency and consequently OPEX

To achieve this, strategy was based on three main axes:

- Separation of project/budgeting activity from construction activity, centralized at a national level and regionally settled respectively

- Rethink and redesign project/budgeting processes enhancing technology usage

- Revue external services hiring strategy

After one year, results of this strategy are visible, with measurable impacts in OPEX but also in customers' satisfaction. However, challenge is not yet over, and relevant initiatives are underway and worth sharing.

Optimizing the Operation of Renewable Energy Communities

Nathalie Friess[1], Ulrich Pferschy[1], Joachim Schauer[2]
[1]University of Graz, Austria; [2]FH Joanneum, Kapfenberg, Austria; ulrich.pferschy@uni-graz.at

Renewable Energy Communities (RECs) allow owners of photovoltaic (PV) systems to share surplus energy in their neighborhood. A main goal of RECs is the optimized use of locally produced energy and thus a load reduction of the higher-level power grid. Better utilization of renewable energy should offer incentives for households to invest in PV systems and thus contributes to the decarbonization of the energy sector.

Main tools for better utilization are load shifting and intelligent battery management. Based on forecasts of (weather dependent) production and consumption profiles, the associated operational decisions can be optimized to improve the overall performance of the community. The strong interdependence between the community members' individual resources prohibits the use of simple heuristic decision rules for this purpose. As actual conditions may well deviate from the forecasts used for optimization, not all optimized decisions will yield the intended outcome. Therefore, we developed a model predictive control inspired planning framework comprising an optimization and a simulation model, which models the actual real-world outcome of the planning decisions for the current time step. The introduced framework can be used to generate realistic performance measures over the course of one year and to reach a better understanding of the benefits of forecast-based coordinated operating strategies in RECs. Moreover, the analysis of different scenarios can be used as a basis for investment decisions, e.g., for houseowners considering the purchase or extension of a PV system or a battery.

Optimizing operation schedules with strict environmental regulations for a network of hydro-electric power plants

Yvonne Blum[1], Sarah Drewes[1], Josef Reis[2], Lukas Zögernitz[2]
[1]The MathWorks, Germany; [2]TIWAG, Austria; yblum@mathworks.com

In 2022 TIWAG (Tiroler Wasserkraft AG), an operator of hydro-electric power plants, integrated a new power plant into their existing network. Increased complexity plus new and extremely rigorous environmental regulations made the established control of their power station network infeasible.

TIWAG needs to ensure energy provision according to the demand forecast, while fulfilling regulatory constraints, such as the limitation of allowed water level gradients in the river. Failing to fulfill these constraints may not only result in penalty fees for TIWAG but can also lead to massive environmental damage.

To solve this, TIWAG and MathWorks Consulting have developed a software solution that regulates the water flow through the power plants and over the weirs into the river, while optimizing the operating schedule. Regulatory constraints can be modeled as nonlinear inequalities.If water flow over the weirs is increased or decreased it must remain constant for several following time steps. Semicontinuous constraints are required to model that the power plant is either switched off (zero water flow) or operating at or above minimal level. Due to the complexity of the nonlinear constraints, we propose an iterative algorithm solving a series of nonlinear optimization problems.

The software is embedded into TIWAG's productive SCADA (Supervisory Control and Data Acquisition) system and triggered every 3 minutes. It fetches the latest prognosis data, simulates the water flow and reservoir levels, and computes an optimized operation schedule for the next 24 hours. These results are directly used to control the power plants.

FC 20: Capital Costs and Investments

Time: Friday, 06/Sept/2024: 10:45am - 12:15pm · *Location:* Theresianum ZG 0670
Session Chair: Christoph Weber

WACCelerating H2 – Impacts of capital cost based regional aggregation on global energy system models

Konrad Telaar, Valentin Bertsch

Chair of energy systems and energy economics, Ruhr-University Bochum, Germany; konrad.telaar@ee.ruhr-uni-bochum.de

The energy transition requires unprecedented levels of global clean energy investments specifically in renewable generation capacity and green hydrogen. Investments in emerging markets and developing economies are disproportionally low despite considerable renewable potential. Insufficient investments in regional renewable generation capacity could lead to higher levelized costs of hydrogen (LCOH), impeding the ramp-up of a global hydrogen market. Conventional energy generation costs are characterized partially by fossil fuel prices, variable costs, while renewable energy and green hydrogen costs are instead characterized by prices of plants, electrolysers and infrastructure, investment costs. This links energy generation costs increasingly to the wide range of capital costs between different countries. Contrasting weighted average costs of capital (WACC) can be observed e.g. between the neighboring South American countries of Chile with 3.5 % and Argentina with 13.8 %, leading to diverging cost and profitability estimations for hydrogen projects. [1]

In this paper the influence of regional WACC variations on global hydrogen production is analyzed in a cost minimizing capacity expansion and unit commitment model. WACC estimates are varied with regional aggregation of the global energy system based on a reference geographical allocation. Then the aggregation is performed by allocating countries based on similar WACC, outlining the influence of cost of capital differences more explicit. Contrasting scenarios, aggregating based on renewable generation profiles and based on hydrogen demand, are used as benchmarks. The results show to what extent cost minimizing strategies shift green hydrogen production to regions with low costs of capital and the impact on LCOH.

Wealth Maximisation and Option to Delay in Residential Energy-Efficiency Investments

Anthony Britto, Joris Dehler-Holland, Wolf Fichtner

Karlsruhe Institute of Technology, Germany; anthony.britto@kit.edu

We propose a model of optimal investment under uncertainty for a wealth-maximising agent who has the option to delay investment in energy efficiency. An extension of the model, where the stochastic energy carrier is switched, e.g. from gas to electricity, is also explored. Exercise boundaries for the optimal stopping problem are estimated numerically for recent case studies of German dwellings. Comparative statics quantify the impact of energy-price uncertainty as well as wealth and income parameters, which have been largely neglected in the literature, on the decision to invest in energy efficiency. An analysis of government policy in this context assesses the effects of carbon taxes, and demonstrates the significant potential for free-riding on energy efficiency subsidies. The effect of increasing correlation between gas and electricity prices on the decision to invest in a heat pump is also explored.

Market equilibria with agent-specific capital costs in energy system models – towards a consistent model formulation

Christoph Weber

University Duisburg-Essen, Germany; christoph.weber@uni-due.de

It is common practice to use linear optimization approaches with a single discount rate in energy system modelling. This is also consistent with the standard central planner interpretation of such models. At the same time, it is well known that outcomes of appropriately formulated optimization models may be interpreted as competitive equilibria. Empirical evidence yet suggest that investors face differentiated capital costs (e.g. Steffen) depending on technology, market and investor characteristics. There have been pragmatic approaches to incorporate such differentiated capital costs into energy system models (e.g. Loulou et al. 2016, Tash et al. 2021, Lonergan et al. 2023). Through a thorough analysis of KKT conditions a theoretically consistent solution may yet be established with succinct and explainable economic features. We illustrate the approach with a stylized application to capacity expansion in Germany.

FC 21: Maritime and Waterway Applications

Time: Friday, 06/Sept/2024: 10:45am - 12:15pm · *Location:* Nordgebäude ZG 1070
Session Chair: Lisa Herlicka

A metaheuristic approach for designing flexible liner shipping networks

Daniel Wetzel, Kevin Tierney
Universität Bielefeld, Germany; daniel.wetzel@uni-bielefeld.de

Liner shipping networks are essential to today's global supply chains, featuring cyclical, periodic services operated by container ships. This cyclical structure makes scheduling easier for both carriers and shippers. However, combining cyclical scheduling with fixed port time slots often leads to inefficient operations. We propose to relax the cyclical assumption and make these networks more flexible by allowing vessels to switch between routes seamlessly, improving efficiency without disrupting container flow. To shippers, the network still appears cyclical and periodic, while carriers can manage a more streamlined network. This change creates an optimization challenge that combines vessel routing and cargo allocation, resulting in complex problem scenarios. We tackle this problem using a metaheuristic approach and show with real-world data that such network flexibility can significantly lower costs compared to traditional fixed schedules.

Location of fueling stations and routing of zero-emission well-boats in the Norwegian aquaculture industry

Sarka Stadlerova, Robin Halseth Aakvik, Kenneth André Inghelm Mørkved, Peter Schütz
Norwegian University of Science and Technology, Norway; sarka.stadlerova@ntnu.no

In this paper, we study the problem of locating hydrogen fueling stations for zero-emission aquaculture vessels in Norway in the area of Lofoten and Vesterålen. We model the problem as location-routing problem considering both the location of hydrogen fueling stations and the routing of aquaculture vessels. The objective is to minimize the total costs while satisfying customers demand. The costs consist of investment costs in fueling stations and fuel costs related to the energy usage of the aquaculture vessels. We formulate the problem as an open route model with energy constraints considering vessels with limited range. A route is defined from an open fueling station to an open fueling station and each vessel can serve at most one route. Therefore, we include a post-processing matheuristic to determine the number of vessels needed to meet the demand. We further conduct a sensitivity analysis on a vessel range. The computational results show that a longer range does not necessarily lead to a lower number of opened fueling stations or a lower number of deployed vessels. However, it leads to structurally different solutions with lower fuel costs and hence lower total costs.

Supply Chain Optimization for Ocean Alkalinity Enhancement

Lisa Herlicka, Frank Meisel
Kiel University, Germany; lisa.herlicka@bwl.uni-kiel.de

Next to the reduction of greenhouse gas emissions, there is already a necessity to remove released CO2 from the atmosphere to limit global warming. The so-called Negative Emission Technologies (NET) are using chemical and biological processes to remove atmospheric CO2 and store it in different mediums. One promising NET is Ocean Alkalinity Enhancement (OAE), which enables the ocean to absorb more atmospheric CO2 by increasing the oceans' alkalinity. Thereby, alkaline minerals like limestone are dissolved in seawater to reinforce the natural chemical process of CO2 absorption. While OAE has already garnered significant attention, with studies exploring its feasibility, social and political acceptance, environmental impacts, risks, and costs, there remains the optimization of an OAE's supply chain. In this talk, we present an optimization model for an OAE supply chain with the objective of minimizing the net present value of corresponding investments and operation costs. The model includes decisions on the extraction site of limestone, the production of the slaked lime at plants, as well as the required transportation and the final discharge of the material at sea using a fleet of ships. A lower limit for CO2 uptake is employed to regulate the emissions from energy and fuels for production and transportation. We present results from a Norwegian case study, examining the cost per sequestered ton of CO2. This approach demonstrates the potential for the future deployment of NET.

FC 22: Road Pricing and Congestion

Time: Friday, 06/Sept/2024: 10:45am - 12:15pm · *Location:* Nordgebäude ZG 1080
Session Chair: Niklas Tuma

Congestion pricing can substitute fuel tax in a world of electric mobility

Thi Ngoc Nguyen, **Felix Müsgens**
Brandenburg University of Technology Cottbus-Senftenberg, Germany; nguyen@b-tu.de

The continued transition towards electric mobility will lead to a substantial decrease in energy tax revenue worldwide, which has implications for government funds. At the same time, demand for transportation is ever increasing, which in turn increases congestion problems. Combining both challenges, this paper assesses the effectiveness of congestion pricing as a substitute for fuel taxes under the assumptions of a dynamic diffusion of electric vehicles. A congestion-based toll that is road-and-time-variant was simulated for the Berlin-Brandenburg region in Germany in 2030 using MATSim. This paper quantifies the impacts of the toll on the governmental revenue, traffic management, environment, social welfare, and the distribution effects. We find that the revenue from a congestion toll can compensate the reduction in passenger car fuel tax. Furthermore, a remarkable welfare surplus is observed, especially when the congestion pricing is coupled with investing in upgrading the roads and subsidising the rails. The toll also shows success in incentivising transport users to adjust their travel behaviour, which reduces traffic delay time by 28–45%. CO_2 emissions as a key metric for decarbonisation of the transport sector decreased substantially. The analysis on the distribution effects suggests that a redistribution plan with a focus on the middle-low-income residents and the outer boroughs could help the policy gain more public acceptance.

Road pricing and spatial distribution of traffic flow in a radial-arc network

Masashi Miyagawa
University of Yamanashi, Japan; mmiyagawa@yamanashi.ac.jp

This paper discusses the effect of road pricing on the spatial distribution of traffic flow. The traffic flow density is derived for a circular city with a radial-arc network. The traffic flow density describes the amount of traffic as a function of position and allows us to identify the location of potential congestion areas. The analytical expression for the traffic flow density demonstrates how the size of the toll area and the toll level affect the spatial distribution of traffic flow. As the size of the toll area increases, the decrease in traffic flow inside the toll area becomes smaller. As the toll level increases, the increase in traffic flow at the boundary of the toll area becomes greater. The effect of the travel cost on the spatial distribution of traffic flow is also examined. These findings can be used to determine the size of the toll area and the toll level required to achieve a certain level of traffic congestion.

An Exact Algorithm for a Capacitated Vehicle Routing Problem with a Zone Tariff

Niklas Tuma[1], **Manuel Ostermeier**[2], **Alexander Huebner**[1]
[1]Technical University of Munich, Germany; [2]University of Augsburg, Germany; niklas.tuma@tum.de

For the cost-efficient supply of stores, it is common in retail practice to rely on third-party logistics providers (3PL) instead of their own fleet. A 3PL carries out the retailers' delivery tours and commonly bills according to a zone-based tariff. This tariff assigns each store to one zone that reflects the travel distances for the delivery. Stores further from the depot are assigned to higher zones. The cost of a tour depends on the furthest zone visited and the volume, subject to discounts. Additionally, 3PLs limit the detour of a tour to ensure economic feasibility. The detour limitation prevents excessive driving within the zones visited. While using 3PLs and their zone tariffs reduces the complexity for retailers, the question arises of how retailers can plan cost-minimal tours that are economical for 3PLs. We address this issue and formalize the problem as a Capacitated Vehicle Routing Problem with a Zone Tariff. The nonlinear tariff and the non-monotonically increasing detour drive the complexity. We provide the first mixed-integer formulation (MIP) for the problem, which we strengthen with valid inequalities. We develop a Branch-and-Check (BAC) decomposition algorithm to solve larger instances and improve it with problem-specific acceleration techniques. In our numerical experiments, we solve a real-world case and adapted instances from the literature. The BAC approach reduces the runtime compared to the MIP by up to three orders of magnitude in selected cases.

Congestion-aware Routing for Intermodal Autonomous Mobility-on-Demand Systems

Jiayue Fan[1], **Dario Paccagnan**[2], **Maximilian Schiffer**[1,3]
[1]School of Management, Technical University of Munich, Germany; [2]Department of Computing, Imperial College London, U.K.; [3]Munich Data Science Institute, Technical University of Munich, Germany; jiayue.fan@tum.de

Urban transportation systems are increasingly overloaded by growing populations, which intensify congestion and subsequently lead to user dissatisfaction, environmental pollution, and health hazards. These challenges highlight the urgent need for more sustainable and efficient mobility solutions. Intermodal autonomous mobility-on-demand systems offer a promising solution to alleviate urban congestion by combining the broad coverage of public transit with the flexibility of on-demand services. Against this background, we study an integer minimum-cost multi-commodity network flow problem with a nonlinear congestion function. We propose an algorithmic framework to route large-scale passenger flows, aiming to determine the system optimum of an intermodal transportation network. This framework employs a layered, time-expanded graph with each layer representing a different transportation mode, and a linearized version of a nonlinear congestion function in the on-demand layer. This structure allows us to apply a column generation approach to derive optimal solutions for the linearized continuous problem and then utilizes a branch-and-price method to obtain integer solutions. Additionally, we develop a rapid rounding algorithm as a faster alternative to the branch-and-price method, aiming to enhance computational efficiency. We validate the performance of our algorithmic framework on a comprehensive urban mobility dataset from Munich, where we solve instances with up to 20618 passengers to optimality. Compared to the branch-and-price method, our rapid rounding algorithm can not only find near-optimal solutions but is significantly faster while ensuring all capacity constraints are satisfied.

FC 23: Traveling Salesman Problems

Time: Friday, 06/Sept/2024: 10:45am - 12:15pm · *Location:* Nordgebäude ZG 1090
Session Chair: Stefan Fedtke

Solving the Time-Dependent Traveling Salesman Problem (TDTSP) with Hexaly

Théo Bordillon

Hexaly, France; tbordillon@hexaly.com

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, primal heuristics. Its modeling formalism can be used to express a wide range of academic and industrial routing problems using list decision variables and lambda functions. These models are very compact, allowing the solver to handle even large-scale problems.

The Traveling Salesman Problem (TSP) is a classic combinatorial optimization problem, but it doesn't capture some operational aspects like temporal dependencies. Unlike the classic TSP where distances between cities are constant, the Time-Dependent TSP (TDTSP) incorporates variable travel times, modeling real-world conditions where travel times depend on the time of day, traffic, or other temporal factors.

Traditionally, this problem is modeled with a discretization of the time horizon and a time matrix for each time step. This matrix can be constructed in various ways, and from it, the rest of the model can be created straightforwardly using Hexaly's list based model. Other problems follow, such as the Time-Dependent Traveling Salesman Problem with Time Windows (TDTSPTW), where points have time windows for visits, and the Time-Dependent Capacitated Vehicle Routing Problem with Time Windows, where multiple capacitated vehicles are available to serve a set of points with demands.

We compare Hexaly's results for the TDTSP and TDTSPTW with those from the literature. Hexaly improves nearly 25% of instances of up to 100 points while maintaining a gap close to 0% on the remaining instances.

Optimal Service Commitments in Traveling Salesman Problems with Stochastic Demand

Lina Schmidt[1], Julian Golak[1], Malte Fliedner[1], Arne Schulz[1,2]

[1]Universität Hamburg, Germany; [2]Helmut-Schmidt-Universität, Germany; lina.schmidt@uni-hamburg.de

In ridepooling services, mobility providers face the considerable challenge to quote expected departure and/or arrival times to customers, who will base their traveling decisions to a significant degree on the promised times. If the service provider communicates very ambitious service commitments, then this will typically increase the likelihood that customers will accept the quoted offer. This, in turn, will make it harder to comply with the commitment without rejecting customers (given limited transportation resources). If the service commitment is less ambitious then customers will be more likely to reject the offer, which will lead to an underutilization of resources and loss in revenue.

In this work, we will analyze the core interdependency between arrival commitments and customer demand in a simplified travelling salesman setting, where all customers share a shuttle to a common destination. After the service provider committed to an arrival time, customers have the opportunity to accept or reject the offer made, where the likelihood of accepting directly depends on the arrival time commitment. After the customer decisions are revealed, an Orienteering Problem needs to be solved in order to keep the arrival time commitment for as many customers as possible. We develop a formal representation of this two-stage stochastic optimization problem and propose exact and heuristic algorithmic approaches for deriving (near) optimal service commitments.

The uncovered traveling salesman problem

Stefan Fedtke, Stefan Schwerdfeger

Friedrich Schiller University Jena, Germany; stefan.fedtke@uni-jena.de

In this paper, we introduce a new variant of the traveling salesmen problem (TSP) called the uncovered TSP (uTSP) with various applications, e.g., in the field of last-mile distribution. Given a set of customers, a depot, and a set of facilities each covering a subset of customers, the task is to select a limited number of facilities, so that the TSP tour through the uncovered customers has minimum cost. We formulate the problem and highlight potential fields of application. Furthermore, we suggest an efficient heuristic solution approach, prove its suitability on different data sets, and provide managerial insights for the application.

FD 01: Closing Session & Plenary Bixby

Time: Friday, 06/Sept/2024: 1:15pm - 2:30pm · *Location:* Audimax
Session Chair: Alexander Martin

History of Computational Progress in LP and MIP

Robert Bixby
Gurobi, United States of America; bixby@gurobi.com

This keynote provides a comprehensive coverage of the history and evolution of linear and integer optimization including corresponding implementations.