



HELMUT SCHMIDT  
UNIVERSITÄT  
Universität der Bundeswehr Hamburg



# OR 2016 HAMBURG

PROGRAM GUIDE & ABSTRACTS

*With program updates (Aug 30)*

INTERNATIONAL CONFERENCE  
ON OPERATIONS RESEARCH –  
ANALYTICAL DECISION MAKING  
HAMBURG, AUG 30 – SEPT 2, 2016

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HELMUT SCHMIDT  
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Universität der Bundeswehr Hamburg



OR 2016

Annual International Conference of the  
German Operations Research Society

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Hamburg, Germany, Aug 30 – Sept 2, 2016

Helmut-Schmidt-Universität /  
Universität der Bundeswehr Hamburg

# Contents

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Welcome.....	v
Greeting.....	vi
Conference History.....	vii
Committees and Contact.....	viii
Schedule.....	ix
Special Sessions.....	x
Proceedings Volume.....	x
Business Meetings.....	xi
Session Organization.....	xi
Internet Access (WLAN).....	xii
Exhibition / Sponsors.....	xii
General Information.....	xii
Pre-Conference Workshops.....	xiii
Tours.....	xiv
Catering.....	xv
Maps.....	xvi
Social Program.....	xvii
Transport in Hamburg.....	xiii
Streams and Stream Chairs.....	xx
Streams, Tracks and Rooms.....	xxi
Plenary Speakers.....	xxiii
Semi-Plenary Speakers.....	xxiv
Technical Program with Abstracts.....	1
- Streams.....	87
- Session Chair Index.....	89
- Author Index.....	94
- Session Index.....	124
Schedule Overview	
Floor Plan Building H1	

# Welcome

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It is our great pleasure to welcome you to OR2016, the Annual International Conference of the German Operations Research Society, which takes place August 30 – September 2, 2016, at the Helmut-Schmidt-Universität / Universität der Bundeswehr Hamburg. The conference theme, Analytical Decision Making, places emphasis on the process of researching complex decision problems and



devising solution methods towards better decisions. This includes classical mathematical optimization, statistics, and simulation techniques, yet more and more such approaches are complemented by methods and tools from computer science for the processing of data and the design and implementation of information systems. Recent advances in information technology enable the treatment of big data volumes and real-time predictive and prescriptive business analytics to drive decisions and actions. Problems are modeled and treated under consideration of uncertainty, risk management, behavioral issues, and strategic decision situations. This necessitates collaborations regarding different scientific areas and application domains. The conference theme is reflected in the opening plenary presentation by Luk N. Van Wassenhove, who will discuss whether current research is relevant and impactful in the important field of humanitarian operations under consideration of classical decision making tools and the special conditions of humanitarian operations. Kurt Mehlhorn will be the plenary speaker on Friday; he will talk about algorithms for computing market clearing prices. In addition, ten semi-plenary speakers will cover important research topics on devising effective solution methods for various domains. The core part of the conference consists of 160 parallel sessions from a broad spectrum of subjects within twenty streams on the theory and practice of operations research. The overall program includes 475 talks and altogether we expect around 700 registered conference participants from about 40 countries. There will be three pre-conference workshops (Tuesday), business track sessions (Wednesday), an exhibition with a number of companies (Wednesday to Friday), industry tours, and an attractive social program in the evenings on Tuesday (Get-Together), Wednesday (Reception), and Thursday (Dinner). Have a good time at OR2016, gain insights, share your expertise with others, recruit your next employees or find your next job, or just enjoy meeting new and old friends that work in the intriguing field of operations research, management science, data science and analytics!

Andreas Fink & Martin J. Geiger  
Conference Chairs

# Greeting

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Dear Participants,

I am delighted to welcome you to the Annual Conference of the German Operations Research Society, GOR e.V., and to your conference site – the Helmut Schmidt University / University of the Armed Forces Hamburg. Our University is an institution beyond compare. We offer a broad set of study programs for the future leaders of the German Armed Forces. About 100 professors, plus 300 research assistants provide 2.200 students with an excellent university education in an accelerated timeline. This takes place on a notable compact University campus, which is clearly an asset for realizing innovative interdisciplinary research.



For many years now, the field of Operations Research is one of the outstanding research areas of our University. To welcome such a renowned international conference is an honor we are especially proud of.

I warmly invite you to discover all the inspiring places this campus has to offer. Due to its harbor Hamburg has a deeply rooted tradition of welcoming people from all parts of the world, of being a place where ideas are interchanged, horizons get broadened and new friends are made. The University will put all its efforts into making this conference your success.

Prof. Dr. rer. nat. Wilfried Seidel

President of the Helmut-Schmidt-Universität / Universität der Bundeswehr Hamburg

# Conference History

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The history of the Annual International Conference of the GOR (Gesellschaft für Operations Research) – sometimes organized cooperatively with other OR societies from Europe – includes the following past stations:

2015	Wien
2014	Aachen
2013	Rotterdam
2012	Hannover
2011	Zürich
2010	München
2009	Bonn (EURO)
2008	Augsburg
2007	Saarbrücken
2006	Karlsruhe
2005	Bremen
2004	Tilburg
2003	Heidelberg
2002	Klagenfurt
2001	Duisburg
2000	Dresden
1999	Magdeburg
1998	Zürich

The GOR was founded 1998 as the fusion of DGOR (Deutsche Gesellschaft für Operations Research) and GMÖR (Gesellschaft für Mathematik, Ökonomie und Operations Research), which already jointly organized a *Symposium on Operations Research* at some years before 1998. In the more distant past these societies organized separate conferences, for example:

- 17th Symposium on Operations Research / Annual Meeting of the Gesellschaft für Mathematik, Ökonomie und Operations Research (GMÖOR), Aug 25–28, 1992; organized by Alexander Karmann, Karl Mosler, Martin Schader, and Goetz Uebe.
- Vierzehnte Jahrestagung der Deutschen Gesellschaft für Operations Research (DGOR), Sept 11–13, 1985; organized by Wolfgang Domschke and Werner Junginger.

These two last mentioned conferences have both been organized at the Universität der Bundeswehr Hamburg. Therefore, this university has now completed the picture, by having hosted the annual conferences of DGOR, GMÖOR, as well as GOR.

# Committees and Contact

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## Program Committee

Andreas Fink (Chair)	Helmut-Schmidt-Universität / Univ. der Bundeswehr Hamburg
Martin J. Geiger (Chair)	Helmut-Schmidt-Universität / Univ. der Bundeswehr Hamburg
Alf Kimms	Universität Duisburg-Essen
Natalia Kliewer	Freie Universität Berlin
Marco Lübbecke	RWTH Aachen
Georg Pflug	Universität Wien
Stefan Pickl	Universität der Bundeswehr München
Anita Schöbel	Georg-August-Universität Göttingen

## Organizing Committee

Claudia Fantapié Altobelli	Helmut-Schmidt-Universität / Univ. der Bundeswehr Hamburg
Andreas Fink (Chair)	Helmut-Schmidt-Universität / Univ. der Bundeswehr Hamburg
Armin Fügenschuh	Helmut-Schmidt-Universität / Univ. der Bundeswehr Hamburg
Martin J. Geiger (Chair)	Helmut-Schmidt-Universität / Univ. der Bundeswehr Hamburg
Ulrich Tüshaus	Helmut-Schmidt-Universität / Univ. der Bundeswehr Hamburg

## Conference Location

Campus of Helmut-Schmidt-Universität / Universität der Bundeswehr Hamburg  
Holstenhofweg 85, 22043 Hamburg

## Contact

Andreas Fink & Martin J. Geiger (andreas.fink@hsu-hh.de, m.j.geiger@hsu-hh.de)  
Fakultät für Wirtschafts- und Sozialwissenschaften  
Helmut-Schmidt-Universität / Universität der Bundeswehr Hamburg  
Holstenhofweg 85, 22043 Hamburg

Web: [or2016.de](http://or2016.de)

E-Mail: [or2016@hsu-hh.de](mailto:or2016@hsu-hh.de)

Twitter: [@or2016de](https://twitter.com/or2016de)





# Schedule

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## **Tuesday (Aug 30, 2016)**

- 14:00–17:00 Pre-Conference Workshops
- 17:00–22:00 Get-Together (Barbecue and Drinks)

## **Wednesday (Aug 31, 2016)**

- 09:00–10:30 WA Opening Ceremony and Plenary (Aula)
- 11:00–12:30 WB Parallel Sessions
- 13:30–15:00 WC Parallel Sessions
- 15:30–16:15 WD Semi-Plenaries
- 16:30–18:00 WE Parallel Sessions
- 19:30–22:30 Reception (International Maritime Museum)

## **Thursday (Sept 1, 2016)**

- 09:00–10:30 TA Parallel Sessions
- 11:00–12:30 TB Parallel Sessions
- 13:30–14:15 TC Semi-Plenaries
- 14:45–16:15 TD Parallel Sessions
- 16:30–18:00 GOR General Meeting
- 19:30–24:00 Conference Dinner (Atlantic Kempinski Hamburg, extra tickets)

## **Friday (Sept 2, 2016)**

- 09:00–10:30 FA Parallel Sessions
- 11:00–11:45 FB Semi-Plenaries
- 11:45–13:15 FC Parallel Sessions
- 13:45–15:00 FD Plenary and Closing Ceremony (Aula)

## **Conference Desk**

This is the central source of information and assistance; in particular, there you receive your conference bag and badge. It is located in the main building H1 of the campus. Opening hours:

- Tuesday: 14:00–20:00
- Wednesday: 08:00–18:00
- Thursday: 08:30–17:00
- Friday: 08:30–15:30

# Special Sessions

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## **GOR Dissertation Prize**

Wednesday (Aug 31), 16:30–18:00 – Hörsaal 5 (Session WE-6)

The prize winners and the presentations are described in the technical program.

## **GOR Master Thesis Prize**

Wednesday (Aug 31), 11:00–12:30 – Seminarraum 101/103 (Session WB-8)

The prize winners and the presentations are described in the technical program.

## **Business Track Sessions**

Wednesday (Aug 31), 11:00–12:40 and 13:30–15:00 – Hörsaal 5 (Sessions WB-6, WC-6)

The presentations are described in the technical program.

## **GOR Unternehmenspreis**

Wednesday (Aug 31), 15:30–16:15 – Hörsaal 5 (Session WD-6)

The prize winner will be announced at the conference opening ceremony.

# Proceedings Volume

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The post-conference proceedings volume will be published by Springer in 2017. About 125 submissions have been received and will be evaluated by the stream chairs and program committee members. Acceptance/rejection notifications are planned for October 2016.

# Business Meetings

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Editorial Board Meeting *OR Spectrum*

- Wednesday (Aug 31), 12:30–14:30, Seminarraum 309 (Building H1)

Program Committee Meeting *OR2017*

- Thursday (Sept 1), 09:00–10:15, Seminarraum 309 (Building H1)

Meeting of the *GOR Working Group Heads*

- Thursday (Sept 1), 10:30–12:00, Thomas-Ellwein-Saal (Building M1, Mensa)

Editorial Board Meeting *Mathematical Methods of Operations Research*

- Thursday (Sept 1), 11:00–12:30, Seminarraum 309 (Building H1)

*GOR General Meeting* (19. Mitgliederversammlung der GOR e.V.)

- Thursday (Sept 1), 16:30, Hörsaal 5 (Building H1)

# Session Organization

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*Speaker Information:* Usually there are three 30-minute presentations (incl. discussion time) within a 90-minute session (with a few exceptions; in particular, in the case of four talks within a session each presentation should last no longer than 20-25 minutes). Lecture rooms are equipped with a computer and video-projector (and microphone if necessary); a technical assistant will be available. Speakers should bring their presentation file on a USB storage device in a common format (ppt/pptx, pdf). The use of one's own computer may also be possible (VGA connection to the video-projector).

*Session Chairs:* The role of the session chair is to ensure the smooth execution of a session. She/he contacts the speakers before the session and begins and closes the session on time. The session chair introduces the speakers and chairs the discussion. Since conference participants may want to jump between the sessions the order of the presentations should not be changed. In case of no shows or last minute cancellations, the assigned time slot should be left empty.

# Internet Access (WLAN)

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Conference participants will receive in their conference bag a so-called 'Eventcamp Ticket' with an individual account which allows to connect devices to the wireless network 'event' with Internet access. Alternatively the wireless network 'eduroam' may be used (in case of an eduroam-account).

# Exhibition / Sponsors

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During the conference there will be an exhibition with the following sponsoring companies:

- ADDITIVE Soft- & Hardware für Technik & Wissenschaft GmbH
- AMPL Optimization Inc.
- GAMS Software GmbH
- Gurobi GmbH
- IBM Deutschland GmbH
- LocalSolver
- Mosek ApS
- Springer-Verlag GmbH, Heidelberg

We are furthermore grateful for the support by:

- DFG – Deutsche Forschungsgemeinschaft
- Helmut-Schmidt-Universität / Universität der Bundeswehr Hamburg
- Lufthansa Technik AG

# General Information

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The regular conference registration includes admittance to all sessions and the exhibition; conference bag/material; coffee, tea, soft drinks, and lunches; admittance to the get-together event (Aug 30) and the reception (Aug 31); wireless internet access at the conference; local transport tickets; Springer proceedings volume (excl. students/retirees).

Phone Numbers: Police 110, Emergencies / Fire 112, Taxis +40 40 666 666 or +49 40 211 211.

# Pre-Conference Workshops

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## **Workshop: GAMS – An Introduction**

Speakers: Frederik Fiand, Tim Johannessen

When/Where: Tuesday (Aug 30), 15:00–17:00, Seminarraum 401/402 (Main Building H1)

This workshop will show you how to use the General Algebraic Modeling System (GAMS) in an efficient and productive way. The key concepts of GAMS and the fundamentals of the language (e.g. sets, data, variables, equations) will be introduced. The largest part of the workshop will consist of hands-on exercises building an optimization based decision support application from scratch, illustrating how GAMS supports an easy growth path from small and simple to larger and more sophisticated models. Along the way we will look at some of the data management tools included in the GAMS system and show how to analyze and debug large problems using the various tools available within GAMS.

## **Workshop: Gurobi – Hands-on Modeling with Python**

Speakers: Sonja Mars, Kostja Siefen

When/Where: Tuesday (Aug 30), 14:00–17:00, Seminarraum 101/103 (Main Building H1)

While Gurobi supports a full range of programming and modeling languages, even experienced users of other languages often tell us how easy it is to use Python to develop and solve optimization models. In this hands-on workshop, we will provide an introduction to Python as well as the Gurobi Python API. We'll then walk through examples illustrating some key concepts, features and benefits of modeling with Python. In addition, we'll cover the use the Gurobi Interactive Shell as well as the Anaconda Python distribution and Jupyter Notebooks. There will be time for questions both during and at the end of this workshop.

## **Workshop: IBM Decision Optimization**

Speakers: John Chaves (IBM Optimization Solutions Architect), Hans Schlenker (IBM Decision Optimization Product Management)

When/Where: Tuesday (Aug 30), 15:00–17:00, Seminarraum 405/406 (Main Building H1)

Part 1 (J. Chaves) – RESTing with IBM Decision Optimization Center (DOC): This session will discuss solve implementation options for DOC-based applications (on-premise vs. DOCplexCloud) and how to integrate or remote-control your DOC applications using the REST API. We'll walk through some existing, live implementations, show a few live examples, and explore what's in the realm of possibilities.

Part 2 (H. Schlenker) – News on IBM DOplexcloud and Decision Optimization Center: We will give you an update on the latest release of IBM Decision Optimization Center (DOC) and IBM Decision Optimization on Cloud (DOplexcloud). We hope that we can excite you a bit – there is quite some pretty cool stuff in it!

# Tours

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On <http://or2016.de/sightseeing.html> we list recommendations for your free time during your stay in Hamburg. Two semi-scientific industry tours are offered free of charge for conference participants (max. one per person); registration was required before the conference. For up-to-date information see <http://or2016.de/tours.html>.

## **Tour 1: Airbus Hamburg-Finkenwerder**

Hamburg-Finkenwerder is the largest Airbus site in Germany with around 12,500 employees. Hamburg is the home of the A320 Family programme management and the A380 major component assembly hall. The tour includes a visit of the component assembly and final assembly of A318/A319/A320/A321 and a tour of the A380 area with a visit to the fuselage structural assembly and cabin equipping hangars of the A380 aircraft.

When: Wednesday afternoon (Aug 31), 16:10–18:40 (on-site tour).

Meeting point: 15:05 (Aug 31) in the coach at the bus roundabout in front of the main building (H1) (at the main entrance of the campus). We will take you to Airbus-Finkenwerder, where we will check-in at the Airbus Periport. Due to security requirements confirmed tour participants have to carry valid identity cards or passports. Participants should be prepared for mainly walking during the visit. The tour is timed so that the coach will directly bring you to the reception afterwards (International Maritime Museum).

## **Tour 2: Lufthansa Technik (Hamburg Airport)**

Lufthansa Technik (LHT) is a leading provider of technical support services for aircraft. Main expertise fields of the business units in the company's base at Hamburg airport are engine overhaul, the conversion of aircraft for private customers, product development and cabin innovations. The tour visits the overhaul hangars and the engine workshops. Special topics may be discussed depending on the interests of the participants.

When: Thursday morning (Sept 1), 10:00–12:30 (on-site tour).

Meeting point: Thursday 09:00 (Sept 1) in the coach at the bus roundabout in front of the main building (H1) (at the main entrance of the campus). Alternatively, you may travel on your own to the bus stop *Lufthansa Basis* (Address: Weg Beim Jäger 193, 22335 Hamburg) in front of the main entrance to the Lufthansa Technik site, where you can hop on our coach at around 09:45. Due to security requirements confirmed tour participants have to carry valid identity cards or passports. Participants should be prepared for partly walking during the visit. At the end of the tour the coach will bring you to the conference venue.

# Catering

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## Coffee Breaks

Coffee, tea, beverages and cakes will be served during the conference in the main building.

## Lunches

Conference participants will receive coupons for taking the lunch in the adjacent mensa. You can select a starter, a main dish with two side dishes, a salad, a dessert, and a soft drink. At least one of the main dishes is vegetarian. The mensa serves food from 11:30 to 13:30. Due to an unexpected delay of renovation works in the mensa building one should, unfortunately, expect queues and delays; therefore, if possible, you may want to avoid the load peak at the beginning of the lunch break time. Considering the shortened lunch break on Friday, we will also offer additional food in the coffee break area on the final day. The prospective mensa menus may contain:

Wednesday (Aug 31):

Starter: Fischfrikadelle (fish cake), Festtagssuppe (eggdrop soup), Salat (salad)

Main dish: Leberkäse (beef and pork loaf), Kesselgulasch, Nudel-Karotten-Lauch-Gratin

Dessert: Mousse au Chocolat, Aprikosenkompott, Milchreis (rice pudding)

Thursday (Sept 1):

Starter: Chicken-Wings, Kartoffelsuppe (potato soup), Salat (salad)

Main dish: Seelachs (pollack), Truthahnroulade (turkey), Pfannkuchen&Pilze (mushroom pancake)

Dessert: Bayerisch Crème mit Mandarinen, Buttermilchdessert, Streuselkuchen

Friday (Sept 2):

Starter: Dill-Happen (herring in dill cream sauce), Fadennudelsuppe (noodle soup), Salat

Main dish: Geflügelbratwurst (poultry), Gyros (Schwein, pork), Makkaroni-Auflauf (pasta)

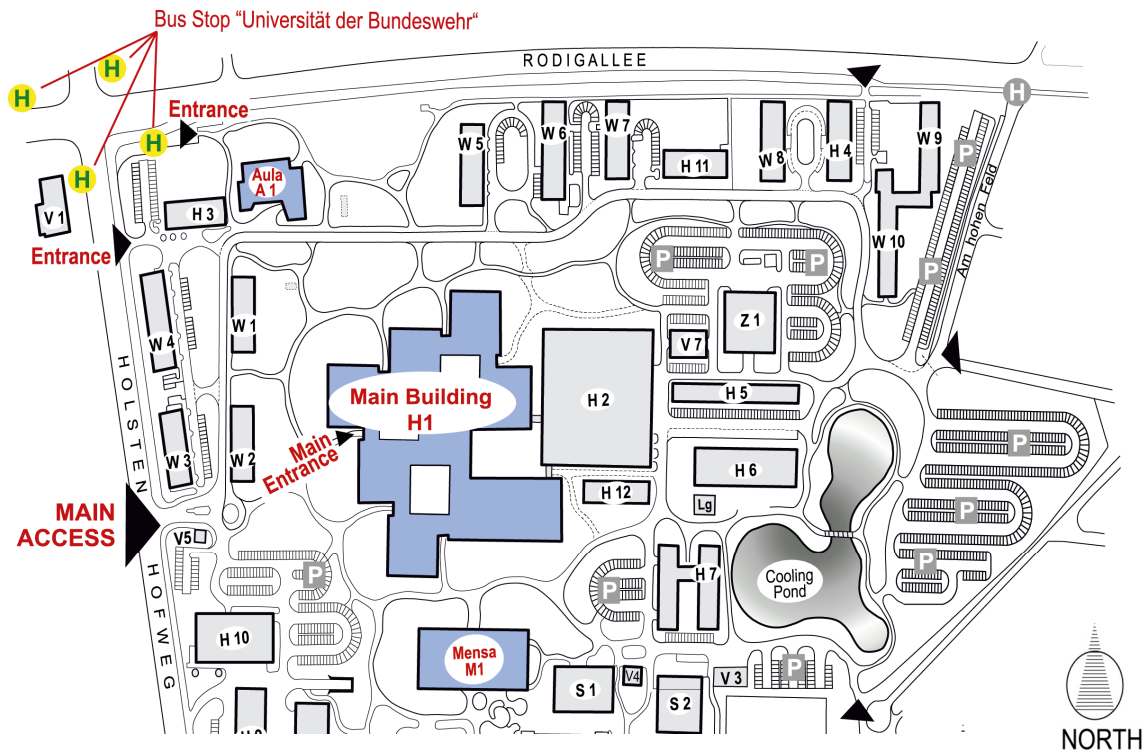
Dessert: Kirschkompott (cherry compote), Mousse au Cappuccino, Obst (fruit)

Please note that there are almost no restaurants in the direct neighborhood of the campus, so it is hardly possible to have lunch outside the campus within the lunch break period.



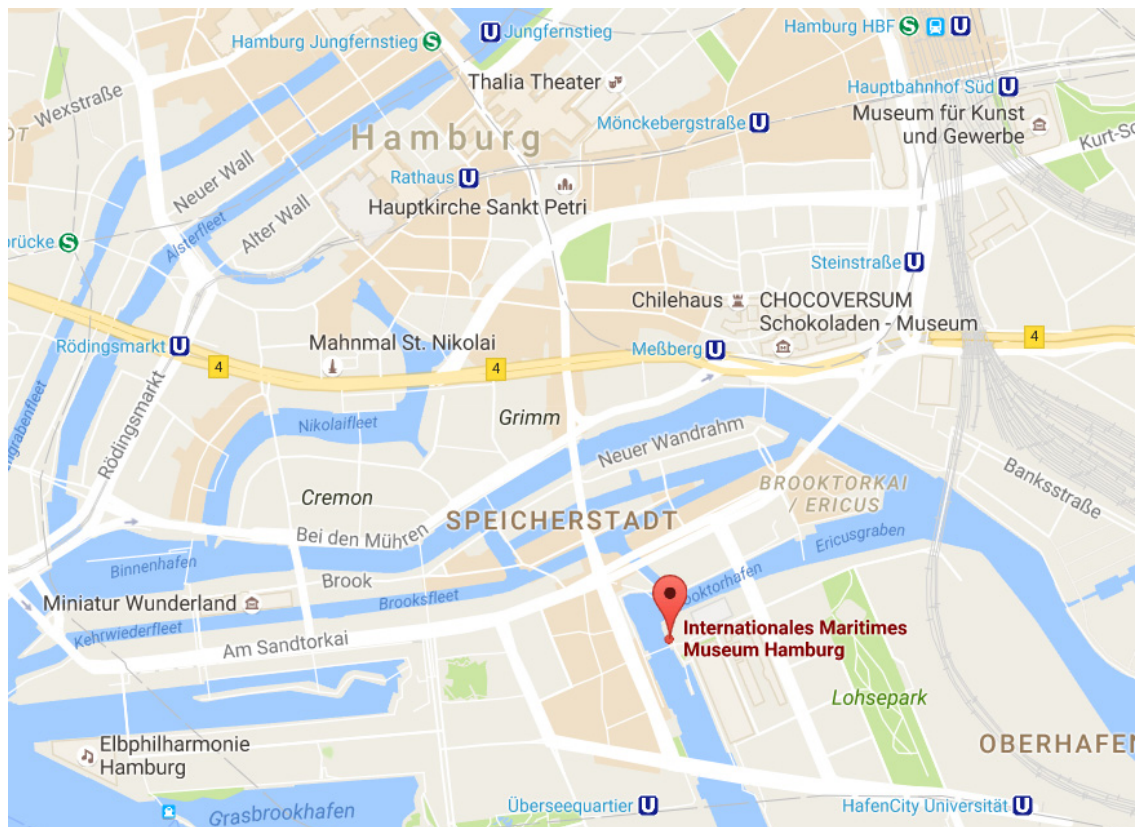
# Maps

**Campus** (see also the detailed map of **building H1** at the back cover of this guidebook)



## Hafencity/Speicherstadt

(with location of the Reception: International Maritime Museum Hamburg)



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# Social Program

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## **Get-Together**

Tuesday (Aug 30), 17:00–22:00, at the forecourt of the Mensa building, directly to the south of the main building (H1), i.e. at the heart of the conference venue.

Before the official opening of the conference, an informal get-together takes place on Tuesday. Check-in at the conference desk will be open during that afternoon/evening. We will welcome you with a barbecue, drinks and beer, so please join us to meet colleagues and friends.

## **Reception**

Wednesday (Aug 31), 19:30–22:30, International Maritime Museum

The reception on Wednesday evening will take place at the International Maritime Museum (IMM), which is housed in the heritage listed building Kaispeicher B (quay warehouse B), right in the center of Hamburg's Speicherstadt (UNESCO World Heritage Site) and Hafencity quarter. The building is the oldest preserved warehouse in Hamburg, built in the neo-Gothic style.

Participation is free of charge for conference participants. Please enjoy the evening with your friends and colleagues. Food and drinks are served on the ground floor as well as on the first and second level. You may also visit all additional 'decks' (9 floors altogether), which display three thousand years' worth of maritime history with precious exhibits, about 50.000 model ships and 4.000 paintings from Peter Tamm's collection.

Address: Koreastraße 1, 20457 Hamburg; U-Bahn (underground train) U4 station *Überseequartier*, (Metro)Bus line 6 stop *Bei St. Annen* or bus line 111 stop *Osakaallee*. Depending on the weather we recommend to walk to the IMM and take a look at the surroundings (Speicherstadt/Hafencity).

## **Conference Dinner**

Thursday (Sept 1), 19:30–24:00, Atlantic Kempinski (extra tickets)

The conference dinner on Thursday evening takes place in the historical Großer Festsaal ballroom at the Atlantic Kempinski Hamburg. This exceptional hotel, which was opened over a century ago for first-class passengers of luxury liners, is a Hamburg landmark. Tickets for the dinner have been sold before the conference, but you may check at the conference desk whether remaining tickets are available for purchase.

Address: An der Alster 72-79, 20099 Hamburg.

# Transport in Hamburg

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The conference location, the campus of the *Helmut-Schmidt-University / Universität des Bundeswehr* is located in the eastern part of Hamburg (Holstenhofweg 85, 22043 Hamburg).

## Public Transport – HVV

Public transport in Hamburg is organized by HVV (Hamburger Verkehrsverbund) with

- underground trains (U-Bahn, which runs underground as well as partly overground),
- rapid transit trains (S-Bahn),
- hundreds of HVV busses,
- certain ferries on the river Elbe.

Conference participants will receive an HVV ticket 'Gesamtbereich (Ringe A-E) inkl. SchnellBus', which is imprinted in the personal badge. This allows to use HVV transport during the conference period at no further cost (after having fetched the badge at the conference desk). For users of mobile devices, HVV connections can be checked at <http://m.hvv.de> or by using an app (available for Android and iPhone).

A usual way to reach the conference venue by public transport from the city center is to use the U-Bahn U1 (blue line, direction *Ohlstedt/Großhansdorf*) to the stop *U Wandsbek Markt* and change there (on bus terminal above ground, Abfahrtsbereich C (departure area C)) to one of the following busses to the bus stop *Universität der Bundeswehr*:

- bus no. 10 (direction *Horner Rennbahn*, bus stop sign reads: <10> AK Wandsbek - Jenfeld Zentrum - Jenfeld (Glatzer Straße)),
- bus no. 261 (direction *Horner Rennbahn*, bus stop sign reads: <261> U Horner Rennbahn - U Burgstraße - U S Berliner Tor),
- bus no. 263 (bus stop sign reads: <263> direction Jenfeld - Barsbüttel - Willinghusen - Stapelf[eld]. - Reinbeker Str./Großlohe)),
- (one may also use bus no. 35 (direction *Sorenkoppel*) to the bus stop *Universität der Bundeswehr*, yet the respective bus stop is outside the bus terminal at Wandsbek Markt (directly to the south)).

Additionally, from the city center one may also use the direct connection by bus no. 35 to the bus stop *Universität der Bundeswehr*, or the U-Bahn U2 (red line) to the stop *Horner Rennbahn* and change there to bus no. 261 (direction *Barmbek*) to the bus stop *Universität der Bundeswehr*. For both connections it is useful to check the schedule due to a cycle time of twenty minutes.

From the airport, one may use the rapid transit train (S-Bahn) S1 which links the airport to the city center every ten minutes. To directly reach the conference from the airport, leave S1 at the stop *U S Wandsbeker Chaussee* (this takes about 16 minutes from the airport) and change, e.g., to bus no. 261 (direction *U Horner Rennbahn*, bus stop sign reads: <261> U Wandsbek M[arkt]. - U Horner Rennb[ahn]. - U Burgstraße - U S Berliner Tor) or bus no. 35 (direction *Sorenkoppel*, bus stop sign reads: <35> U Wandsbek Markt - Jenfeld - Rahlstedt (Ost)) to the bus stop *Universität der Bundeswehr*.

### **By Car, Taxi and Car-Sharing**

To reach the conference location by car drive to the address *Holstenhofweg 85, 22043 Hamburg* and enter the campus gateway. For parking on the campus, please register at the campus gateway (gatehouse), where you will receive directions for the parking area. A taxi trip from the city center may cost approx. 25 €. In Hamburg there are also several car-sharing services such as car2go, DriveNow, and Flinkster.

### **Travel to Hamburg**

Long-distance trains (ICE/IC) stop at several train stations in Hamburg. Usually conference participants would go to *Hamburg Hauptbahnhof* (Hbf) (main train station), one of the busiest stations in Europe. Train tickets are available at Deutsche Bahn (DB).

Hamburg Airport (IATA-code: HAM) features direct flights to more than one hundred destinations. The airport is known in German as *Flughafen Hamburg*. The airport is located 8 km north of the city center in the Fuhlsbüttel quarter.

HVV, the Hamburg public transit network, runs the rapid transit train (S-Bahn) S1 which links the airport to the city center every ten minutes. To directly reach the conference from the airport, leave S1 at the stop *U S Wandsbeker Chaussee* (this takes 16 minutes from the airport) and change, e.g., to bus no. 261 (direction *U Horner Rennbahn*) or bus no. 35 (direction *Sorenkoppel*) to the bus stop *Universität der Bundeswehr*.

Several long-distance busses approach Hamburg's main bus-port, the ZOB, which is located next to the main train station (Hauptbahnhof). Coach operators such as MeinFernbus FlixBus, Postbus, Berlin Linien Bus, and others offer connections to many other cities in Germany and Europe.

From all directions there is an Autobahn that leads to Hamburg. To reach the conference location from the eastern side of Hamburg, one may use *Autobahn A24 exit Hamburg-Jenfeld*, travel *Schiffbeker Weg* heading north until *Rodigallee*, turn left, follow Rodigallee and turn left to the campus gateway at *Holstenhofweg 85*. For parking on the campus, please register at the campus gateway (gatehouse), where you will receive directions for the parking area.

# Streams and Stream Chairs

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Business Analytics and Forecasting	Sven F. Crone, Thomas Setzer
Control Theory and Continuous Optimiz.	Dmitry Ivanov, Christiane Tammer
Decision Theory a. Multi Crit. Decision Making	Jutta Geldermann, Kathrin Klamroth
Discrete and Integer Optimization	Christoph Buchheim, Marco Lübbecke
Energy and Environment	Peter Letmathe, Dominik Möst
Finance	Michael Breitner, Daniel Rösch
Fuzzy Systems and Artificial Intelligence	Heinrich Rommelfanger, H.-G. Zimmermann
Game Theory and Experimental Economics	Tobias Harks, Guido Voigt
Graphs and Networks	Armin Fügenschuh, Sven O. Krumke
Health Care Management	Jens O. Brunner, Teresa Melo
Logistics, Routing and Location Planning	Stefan Irnich, Herbert Kopfer
Metaheuristics	Franz Rothlauf, Stefan Voß
Optimization under Uncertainty	Achim Koberstein, Anita Schöbel
Pricing and Revenue Management	Catherine Cleophas, Claudius Steinhardt
Production and Operations Management	Malte Fliedner, Raik Stolletz
Project Management and Scheduling	Dirk Briskorn, Florian Jaehn
Security and Disaster Management	Matthias Dehmer, Stefan Ruzika
Simulation and Stochastic Modeling	Michael Manitz, Martin Zsifkovits
Supply Chain Management	Herbert Meyr, Stefan Minner
Traffic and Passenger Transportation	Natalia Kliewer, Marie Schmidt
Software and Modelling Systems	Andreas Fink
Business Track	Andreas Fink, Martin J. Geiger

# Streams, Tracks and Rooms

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Business Analytics and Forecasting	Track 20 (Room 404)
Control Theory and Continuous Optimiz.	Track 13 (Room 204)
Decision Theory a. Multi Crit. Decision Making	Track 14 (Room 206)
Discrete and Integer Optimization	Tracks 2, 3 (Hörsäle 1, 2)
Energy and Environment	Tracks 3, 4 (Hörsäle 2, 3)
Finance	Track 9 (Room 105)
Fuzzy Systems and Artificial Intelligence	
Game Theory and Experimental Economics	Tracks 5, 7 (Hörsäle 4, 6)
Graphs and Networks	Track 7 (Hörsaal 6)
Health Care Management	Track 16 (Room 308)
Logistics, Routing and Location Planning	Track 8, 18, 21 (Rooms 101/103, 401/402, 405/406)
Metaheuristics	Track 12 (Room 202)
Optimization under Uncertainty	Track 10 (Room 108)
Pricing and Revenue Management	Tracks 6, 10 (Hörsaal 5, Room 108)
Production and Operations Management	Track 11 (Room 110)
Project Management and Scheduling	Tracks 15, 16 (Rooms 305, 308)
Security and Disaster Management	Track 9 (Room 105)
Simulation and Stochastic Modeling	Tracks 13, 14 (Rooms 204, 206)
Supply Chain Management	Track 17 (Room 310)
Traffic and Passenger Transportation	Tracks 19, 20 (Rooms 403, 404)
Software and Modelling Systems	Track 9 (Room 105)
Business Track	Track 6 (Hörsaal 5)



# Plenary Speakers

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The abstracts of the presentations are given in the technical program.

Opening – Wednesday (Aug 31), 09:00–10:30 – Aula

**Luk N. Van Wassenhove** INSEAD, Belgium/France

***Perspectives on Research in Humanitarian Operations***

*Professor Van Wassenhove's recent research focus is on closed-loop supply chains (product take-back and end-of-life issues) and disaster management (humanitarian logistics). He publishes regularly in Management Science, Production and Operations Management, and many other academic as well as management journals (like Harvard Business Review, and California Management Review). He is the author of many award-winning teaching cases and regularly consults for major international corporations. In 2005, Professor Van Wassenhove was elected Fellow of the Production and Operations Management Society (POMS). In 2006, he was the recipient of the EURO Gold Medal for outstanding academic achievement. In 2009 he was elected Distinguished Fellow of the Manufacturing and Services Operations Management Society (MSOM), and received the Lifetime Achievement Faculty Pioneer Award from the Academy of Business in Society (ABIS) and the Aspen Institute. In 2013 he became Honorary Fellow of the European Operations Management Association (EurOMA). He is a member of the Royal Flemish Academy of Sciences. Before joining INSEAD he was on the faculty at Erasmus University Rotterdam and Katholieke Universiteit Leuven. At INSEAD he holds the Henry Ford Chair of Manufacturing. He created the INSEAD Social Innovation Centre and acted as academic director until September 2010. He currently leads INSEAD's Humanitarian Research Group.*



Closing – Friday (Sept 2), 13:45-15:00 – Aula

**Kurt Mehlhorn**

Max-Planck-Institut für Informatik, Universität des Saarlandes

***Network Flow and Equilibrium Computation  
in the Linear Exchange Economy***

*Kurt Mehlhorn is a Director of the MPI for Informatics and Professor of Computer Science at Saarland University. He heads the algorithms and complexity group at the MPI for Informatics. He co-authored some 300 publications in the field, published six books, and is one of the people behind the LEDA software library. He graduated more than 80 students, many of whom have now faculty positions. He has received several prizes (Leibniz Award, EATCS Award, ACM Paris Kanellakis Theory and Practice Award, Erasmus Medal of the Academia Europaea) for his work. He holds Honorary Doctorate Degrees from Magdeburg, Waterloo, Aarhus and Gothenburg universities and is an ACM Fellow. He is a member of the German Academy of Sciences Leopoldina, Academia Europaea, the German Academy of Science and Engineering acatech, the US Academy of Engineering, and the US Academy of Science. From 2002 to 2008, he was vice president of the Max Planck Society. He is a co-founder of Algorithmic Solutions Software GmbH.*



# Semi-Plenary Speakers

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The abstracts of the presentations are given in the technical program.

Wednesday (Aug 31), 15:30–16:15 – Hörsaal 3 (WD-04)

**Johan Marklund** Lund University, Sweden

***Sustainable Supply Chain Inventory Control***

Johan Marklund is Professor of Production Management at Lund University, Faculty of Engineering, in Sweden. He has previously worked at the Leeds School of Business, University of Colorado, Boulder, and the Boston Consulting Group. He holds degrees from Linköping University (MSc), and Lund University (BSc and PhD). His research interests include inventory theory, supply chain management and logistics. A special emphasis is placed on stochastic multi-echelon inventory problems, lately with applications in the sustainability area with focus on integrated control of inventory and transportation decisions.



Wednesday (Aug 31), 15:30–16:15 – Hörsaal 1 (WD-02)

**Kaisa Miettinen** University of Jyväskylä, Finland

***Advantages of Interactive Multiobjective Optimization Methods Demonstrated with NAUTILUS Navigator enabling Navigation without Trading-Off***

Kaisa Miettinen is Professor of Industrial Optimization at the Department of Mathematical Information Technology, University of Jyväskylä in Finland. She is also vice-rector of the University of Jyväskylä. In this position she chairs the science council and the graduate school for doctoral studies. She received her Ph.D. and M.Sc. degrees at the Department of Mathematics of the University of Jyväskylä in 1994 and 1988, respectively. Her research interests include theory, methods, applications and software of nonlinear multiobjective optimization including interactive and evolutionary approaches and she heads the Research Group on Industrial Optimization. She has authored about 150 refereed journal, proceedings and collection papers and over 80 reports, edited 13 proceedings, collections/special issues and written a monograph Nonlinear Multiobjective Optimization. She is the Immediate-Past President of the International Society on Multiple Criteria Decision Making and has also chaired EUROPT, the EURO Working Group on Continuous Optimization and the Finnish Operations Research Society. She belongs to the editorial boards of six international journals and is subject editor in mathematics of the journal Optimization and Engineering. She belongs to the Steering Committee of Evolutionary Multi-Criterion Optimization and is a member of the IEEE Computational Intelligence Society Task Force Group on Multiobjective Evolutionary Algorithms. She has worked at IIASA, International Institute for Applied Systems Analysis in Austria, KTH Royal Institute of Technology in Stockholm, Sweden and at Helsinki School of Economics in Finland.





She was the Chair of the 21st International Conference on Multiple Criteria Decision Making in 2011. She was the program chair of the 23rd International Conference on Multiple Criteria Decision Making which was held in Hamburg in 2015. She has also been the co-organizer of four Dagstuhl seminars devoted to fostering collaboration between multiple criteria decision making and evolutionary multiobjective optimization researchers. She is a member of the Finnish Academy of Science and Letters, Section of Science, she has been awarded the Väisälä Award of the Finnish Academy of Science and Letters in the field of mathematics in 2009 and she was chosen as Researcher of the Year at Helsinki School of Economics in 2007.

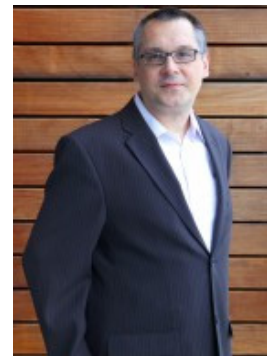
Wednesday (Aug 31), 15:30–16:15 – Hörsaal 2 (WD-03)

**Gerhard J. Woeginger**

Eindhoven University of Technology, The Netherlands

***New answers to old questions on the TSP***

Gerhard J. Woeginger is a professor at the Eindhoven University of Technology, where he chairs the combinatorial optimization group in the department of mathematics and computer science. His research interests lie in the intersection area of Operations Research, Theoretical Computer Science, and Discrete Mathematics. Woeginger was program chair of the European Symposium on Algorithms (ESA-1997), the International Colloquium on Automata, Languages and Programming (ICALP-2003), the European Conference on Operational Research (EURO-2009), the International Computer Science Symposium in Russia (CSR-2016), and of several other conferences. He received a Humboldt Research Award in 2011, and he was elected to the Academia Europaea in 2014.



Thursday (Sept 1), 13:30–14:15 – Hörsaal 2 (TC-03)

**Jose R. Correa** Universidad Chile

***Dynamic pricing with forward-looking consumers***

Jose Correa is a Professor of Industrial Engineering at Universidad de Chile. He graduated as a Mathematical Engineer from Universidad de Chile in 1999 and obtained a PhD in Operations Research from MIT in 2004. His research, focusing in combinatorial optimization and game theory, has been rewarded with some important prizes (such as the TSL best paper award, Tucker prize finalist). Jose serves in the editorial board of Operations research and Mathematical Programming B and has been in the PC of a number of conferences.



Thursday (Sept 1), 13:30–14:15 – Hörsaal 3 (TC-04)

**Johann Hurink** University of Twente, The Netherlands  
***Decentralized Energy Management: New Challenges for Operations Research***



Johann L. Hurink received the Ph.D. degree from University of Osnabrück (Germany) in 1992 for a thesis on a scheduling problem occurring in the area of public transport. From 1992 until 1998 he has been an assistant professor at the same university working on local search methods and complex scheduling problems. This work resulted in a Habilitation thesis at the University of Osnabrück in 1999. From 1998 until 2009 he has been an assistant and associated professor in the group Discrete Mathematics and Mathematical Programming at the department of Applied Mathematics at the University of Twente.

Since 2009 he is a full professor of the same group and since 2010 also the Director of the Dutch Network on the Mathematics of Operations Research (LNMB). He has published more than 100 refereed papers in international journals and conferences and has been involved in several European and national research projects. Current work includes the application of optimization techniques and scheduling models to problems from decentralized energy management, logistics, and health care.

Thursday (Sept 1), 13:30–14:15 – Hörsaal 5 (TC-06)

**Frits C.R. Spieksma** Katholieke Universiteit Leuven, Belgium  
***Scheduling a soccer league***



Frits Spieksma is a professor of Operations Research at the Faculty of Business and Economics of KU Leuven (Belgium). He is interested in combinatorial optimization problems, both from a theoretical point of view, as well as from a practical point of view. He has a specific interest in sport scheduling problems, and initiated a EURO Working Group on this subject. He has coauthored over 80 research papers, and serves on the board of several OR journals.

Thursday (Sept 1), 13:30–14:15 – Hörsaal 1 (TC-02)

**Grit Walther** RWTH Aachen

***OR for Future Mobility: Designing Sustainable Means of Transportation***

Grit Walther holds a Diploma in Geoecology (1999) and a PhD in Business Administration (2004) from Technische Universität Braunschweig. In 2009 she finished her habilitation with a thesis on "Sustainable Supply Chains". After being professor for Production and Logistics at Bergische Universität Wuppertal (2010 to 2012), she is since 2012 full professor and head of the Chair of Operations Management at RWTH Aachen University.



Her research focuses on application-oriented, techno-economic modelling and evaluation of logistics and production systems as well as supply chains with specific emphasize on sustainability aspects. Current research topics are network planning for recycling and reverse logistics systems, design and management of sustainable supply chains, as well as design of sustainable mobility systems.

Grit Walther is member of the strategy board of RWTH Aachen University, head of the scientific commission on "Sustainability Management" of the VHB and coordinating board member of the EURO Working Group on "Sustainable Supply Chains".

Friday (Sept 2), 11:00–11:45 – Hörsaal 1 (FB-02)

**Robert Klein** Universität Augsburg

***Revenue Management: Selected Concepts and Applications***

After both, studying Business Administration and Information Systems as well as working as a research assistant at the Technical University of Darmstadt, Robert Klein became a full Professor at the University of Augsburg in 2006. There he holds the chair for Analytics & Optimization, representing the first chair in Germany being explicitly devoted to the trend toward more data, more algorithmic analysis of it, and more orientation to model-based and fact-based decision making.



Robert has been involved in research and development in the areas of pricing and revenue management, analytical customer relationship management, and operations research. He is excited in solving real-world problems by analytics and, therefore, is very much interested in transferring results of his team's research to industry. He has done projects in cooperation with Daimler, IBM, Lufthansa Systems, Sixt, and TUI, with most of the projects having a strong emphasis on analytical pricing. He has published in journals such as Computers & Operations Research, European Journal of Operational Research, INFORMS Journal on Computing, Omega, OR Spectrum, or Transportation Science. He is the co-author of several textbooks on business mathematics, operations research, and revenue management.

Friday (Sept 2), 11:00–11:45 – Hörsaal 2 (FB-03)

**Rüdiger Schultz** Universität Duisburg-Essen

***Stochastic Programs in Gas and Power Networks***

Rüdiger Schultz is a Full Professor for Discrete Mathematics and Optimization in the Department of Mathematics at the University of Duisburg-Essen, Germany, since 1998. His doctoral and habilitation degrees in Mathematics he has received from the Humboldt University Berlin in 1985 and 1995. Dr. Schultz' primary research interests are in optimization under uncertainty, discrete optimization, and in industrial applications of mathematical optimization. His research accomplishments include seminal results on structure, stability, and algorithmic treatment of stochastic programs, in particular of models involving integer variables, risk aversion, and, more recently, also PDE constraints. He has made contributions to real-life applications of mathematical optimization in the power, natural gas, and chemical processes industries. He has co-authored more than 100 scientific papers. Currently, Dr. Schultz is Editor-in-Chief of the journal "Computational Management Science" and Area Editor Linear and Stochastic Optimization of "Operations Research Letters". He is serving as a member of the editorial boards of five further research journals in mathematics.



Friday (Sept 2), 11:00–11:45 – Hörsaal 5 (FB-06)

**Kenneth Sörensen** University of Antwerp, Belgium

***A history of metaheuristics***

Kenneth Sörensen is professor at the Faculty of Applied Economics of the University of Antwerp, where he also obtained his PhD. Kenneth Sörensen chairs the research group ANT/OR (University of Antwerp Operations Research Group), a group that focuses on applications of Operations Research in diverse domains, and on the development of optimization algorithms, especially metaheuristics.



Kenneth Sörensen has published extensively on applied (heuristic) optimization and is a leading expert on the development of metaheuristics. He also founded the largest working group on metaheuristics: EU/ME - the metaheuristics community.

## Wednesday, 9:00-10:30

### ■ WA-01

Wednesday, 9:00-10:30 - Aula

#### Opening Ceremony and Plenary Lecture

Stream: Plenaries

Chair: *Andreas Fink*

Chair: *Martin Josef Geiger*

#### 1 - Perspectives on Research in Humanitarian Operations

*Luk Van Wassenhove*

Research in Humanitarian Operations has increased exponentially in recent years with hundreds of papers, several books and quite a few survey articles. At the same time, the problems faced by humanitarian organizations have grown in complexity. Their case load has increased substantially and funding is being reduced. The type and frequency of disasters changes (e.g. due to climate change and urbanization) and technology offers new perspectives (e.g. social media or drones). It is therefore important to ask the question whether current research is relevant and impactful, and what are burning research questions. Humanitarian Operations take place in specific contexts that are often very different from commercial operations: destroyed infrastructure, failing information systems, insufficient funds and assets, dynamic and chaotic situations, multiple stakeholders with diverging objectives, conflicts and fighting parties, security issues, and so on. It is therefore crucial to understand the impact these contextual elements may have on the problem at hand and whether our standard OR tools are readily applicable or not. In many cases, they are not, i.e. new approaches and perhaps methodologies are needed. In short, a new science of humanitarian operations needs to be developed to provide support in conditions where our classical tools simply do not apply. The first principle of humanitarian operations is "Do no harm". It is very tempting to use our classical OR tools and state the results will help humanitarians. The truth, however, is that without proper knowledge of the context, the outcomes of our tools can easily be misleading or even downright wrong. Context is important and in this research area, perhaps more than in many other ones, it is fundamental to carefully check assumptions, data, method, and output with humanitarian experts, to triangulate things and verify results and potential impact before making strong claims or recommendations. This presentation will attempt to present the specific context of humanitarian operations, introduce some key issues and research questions, and illustrate these with some examples from successful studies.

## Wednesday, 11:00-12:30

### ■ WB-02

Wednesday, 11:00-12:30 - Hörsaal 1

#### Exact Approaches for Mixed-Integer Nonlinear Optimization (i)

Stream: Discrete and Integer Optimization

Chair: *Frauke Liers*

#### 1 - Global Optimization of Ideal Multi-component Distillation Processes by Problem specific Bound Tightening

*Nick Mertens, Achim Kienle, Christian Kunde, Dennis Michaels*

A central question in chemical engineering deals with determining a cost-optimal design of separation processes. Such questions can be formulated as mixed integer non-linear optimization problems, that have to be solved to global optimality. That task is, in general, extremely hard and costly in terms of time. Therefore, there is a need to develop problem specific optimization techniques.

In this work we focus on multi-component distillation columns with constant relative volatilities. We apply a suitable variable transformation resulting in a monotonic structure that enables us to strengthen the model formulation, and allows us to define a problem specific bound tightening procedure which can be incorporated in a branch and bound based global optimization framework. We provide computational results that demonstrate the influence of the bound tightening procedure. In particular, the results show a reduction of the solution time compared to the standard model formulation.

#### 2 - Multiple Choice Problems under Staircase Compatibility

*Maximilian Merkert, Andreas Bärmann, Thorsten Gellermann, Oskar Schneider*

We consider a multiple choice feasibility problem where the items chosen in a solution have to fulfill a given pairwise compatibility relation. This is motivated by two applications where such a problem is contained as a substructure. One of them is on optimization of railway timetables while the other is in the context of piecewise linearization of nonlinear problems on transportation networks. In this talk, we focus on structural properties of the problem. Our definition of staircase compatibility generalizes a common property of both special cases which allows for a totally unimodular linear programming formulation of linear size. Furthermore, computational results show that for the two applications mentioned above, there is great benefit from using those totally unimodular reformulations for representing the inherent multiple choice substructure.

#### 3 - Penalty Alternating Direction Methods for Mixed-Integer Optimization: A New View on Feasibility Pumps

*Martin Schmidt, Bjoern Geissler, Antonio Morsi, Lars Schewe*

Feasibility pumps are highly effective primal heuristics for mixed-integer linear and nonlinear optimization. However, despite their success in practice there are only few works considering their theoretical properties. We show that feasibility pumps can be seen as alternating direction methods applied to special reformulations of the original problem, inheriting the convergence theory of these methods. Moreover, we propose a novel penalty framework that encompasses this alternating direction method, which allows us to refrain from random perturbations that are applied in standard versions of feasibility pumps in case of failure. We present a convergence theory for the new penalty based alternating direction method and compare the new variant of the feasibility pump with existing versions in a numerical study for mixed-integer linear and nonlinear problems.

## ■ WB-03

Wednesday, 11:00-12:30 - Hörsaal 2

### Exact Algorithms for Hard Combinatorial Optimization Problems

Stream: Discrete and Integer Optimization

Chair: *Joost de Kruijff*

#### 1 - Recursively stacking items with variable height in a tube packing application

*Stephen Maher, Ambros Gleixner, Benjamin Müller, Joao Pedro Pedroso*

Tubes of various diameters and lengths are packed into the one container for transportation. Given the different lengths and the possibility to stack smaller tubes on larger ones introduces a difficult stacking/packing problem. Currently only heuristic approaches are available to solve the tube packing problem, which combines aspects of the bin packing, cutting stock and knapsack problems. An exact solution approach will be presented that is developed from a unique graph formulation of the packing problem. Using properties from the graph formulation, column-and-row generation is applied. This talk will demonstrate the ability of the graph formulation and column-and-row generation solution algorithm is capable of producing exact solutions for many difficult tube packing problems.

#### 2 - A Parallel Branch-and-Price Algorithm for Unrelated Parallel Machine Scheduling with Setup Times in High Performance Computing Environments

*Gerhard Rauchecker, Guido Schryen*

Scheduling problems are essential for decision making in many academic disciplines, including operations management, computer science, and information systems. Since many scheduling problems are NP-hard in the strong sense, there is only limited research on exact algorithms and how their efficiency scales when implemented on parallel computing architectures. We address this gap by (1) modeling a strongly NP-hard parallel machine scheduling problem on unrelated machines with sequence- and machine-dependent setup times by means of a binary linear program, (2) adapting an exact branch-and-price algorithm to solve the model, (3) improving the adapted algorithm, (4) parallelizing the improved algorithm using state-of-the-art shared-memory and distributed-memory parallelization paradigms, and (5) conducting extensive computational experiments in a modern high performance computing (HPC) environment. With our experiments, we show that both parallelization approaches can be combined straightforwardly and that execution times can be reduced substantially so that even moderately large-scale instances with up to 1,000 jobs on up to 1,000 machines can be solved in a modern HPC environment in less than one minute. Furthermore, we found that the relative impact of both parallelization types varies with instance sizes. These insights result in size-dependent recommendations for researchers and practitioners who need to select a suitable HPC environment that solves their particular problem instances most efficiently.

#### 3 - Integer programming models for the mid-term production planning of high-tech low-volume industries

*Joost de Kruijff, Cor Hurkens, Ton de Kok*

We studied the mid-term production planning of high-tech low-volume industries. Mid-term production planning (6 to 24 months) allocates the capacity of production resources to different products over time and coordinates the associated inventories and material inputs so that known or predicted demand is met in the best possible manner. High-tech low-volume industries can be characterized by the limited production quantities and the complexity of the supply chain. Our MILP models can handle general supply chains and production processes that require multiple resources. Furthermore, they support semi-flexible capacity constraints and multiple production modes.

First, we introduce a model that assigns resources explicitly to release orders. Resulting in a second model, we introduce alternative capacity constraints, which assure that the available capacity in any subset of the planning horizon is sufficient. Since the number of these constraints is exponential we solve the second model without any capacity constraints. Each time an incumbent is found during the branch and bound process a maximum flow problem is used to find missing constraints. If a missing constraint is found it is added and the branch and bound process is restarted. Results from a realistic test case show that utilizing this algorithm to solve the second model is significantly faster than solving the first model.

## ■ WB-04

Wednesday, 11:00-12:30 - Hörsaal 3

### Model Based Energy System Planning

Stream: Energy and Environment

Chair: *Hannes Hobbie*

#### 1 - Optimal Renewable Energy Deployment in Germany - Combining Portfolio Theory with Fundamental Electricity Market Modelling

*Hannes Hobbie, Dominik Möst*

Germany's electricity system is currently undergoing significant changes with substantial investments in renewable energy capacities. In this context, it is of interest to determine where to install which generation capacities and how to configure optimal portfolios. Optimal portfolios not only consider the local generation cost, but also take into account that the stochastic nature of renewables increases cost for electricity supply. When modelling investment decisions with fundamental market models these interactions are endogenously part of the solution. However, high computational requirements limit the granularity of renewable energy representation. An alternative approach with less computational effort involves Mean Variance Portfolios (MVP). The basic idea is to minimise the variance of any desired level of expected portfolio return composing of different assets, taking into account that a higher return is coupled with a higher risk, which is represented by a higher variance of expected return. This approach can be transferred to energy system planning in such a way, that an optimal combination of fluctuating feed-in from different regional locations and renewable technologies can lead to a reduced fluctuation of the total feed-in and hence smoothen the residual load. In this contribution, the expansion of renewable capacities in Germany is modelled applying MVP. In a second step, the capacities from the MVP approach are taken to calculate and analyse system price effects with a fundamental electricity market model which derives the cost optimal power plant dispatch with an hourly resolution for a one year time-frame. Results will show the optimal regional and technologic composition of renewable energies and their impact on system costs in the near future.

#### 2 - Interaction of power plant dispatch and capacity expansion models for the European energy system considering high shares of intermittent sources

*Hasan Ümitcan Yılmaz, Quentin Bchini, Dogan Keles*

In the context of growing wind and PV capacity in Europe, the fluctuation of renewables and the flexibility of conventional power plants must be modelled applying a high time resolution. However, increasing time resolution affects the complexity and the execution time of the model exponentially as a high number of variables are related to the time structure. The aim of this study is to find ways to increase the complexity of the model only where it is necessary, while simplifying the problem elsewhere. The main necessity in this analysis is to model volatile electricity feed-in and dispatch more accurately. Therefore, an optimization model for the European power system (PERSEUS-EU) has been split into two different models: a detailed dispatch model which optimizes the hourly resolved unit commitment for a whole year and a capacity expansion model which optimizes the capacity expansion and unit commitment, but in this case only for representative time slices. Afterwards, an algorithm is developed to couple both models. First, the results of the expansion model for year  $t$ , among others the power plant capacity, is turned to the dispatch model which optimizes the unit commitment of that year. If the energy mix derived from both models does not converge, the energy mix generated with the dispatch model is used as input/requirement within the expansion model. Afterwards a new iteration with the described interaction of both models is started. If a certain level of convergence in the results of both models is reached, the iteration loop is stopped. The same procedure is used for the forthcoming years  $t+i$  to  $T$ . Such a modelling environment allows among others an in-depth assessment of the need for flexibility options without affecting considerable the execution time.

### 3 - Linearized Optimization Models for Decentralized Energy Supply Systems

*Martin Comis, Björn Bahl, Andre Bardow, Arie Koster, Sebastian Goderbauer*

Decentralized energy systems have advanced to a highly popular concept to satisfy the demand for local, sustainable and cost-efficient energy. The problem of synthesizing such energy systems by combining units of various energy conversion technologies in order to meet time-varying electric and thermal demands is addressed by the Decentralized Energy Supply System Synthesis Problem (DESSSP). To account for the nonlinear investment costs and part-load performance of the involved energy conversion technologies, the DESSSP is naturally modeled as mixed-integer nonlinear program (MINLP). In this talk we present different mixed-integer linear programs (MILP) for the DESSSP obtained through appropriate reformulation and approximation by means of (multivariate) piecewise linearization techniques. We identify four classes of embedded nonlinearities and develop tailored reformulation strategies exploiting present structures. Moreover, we point out a mutual influence between two considered energy conversion technologies which necessitates a separate consideration of one of these classes in the first place. Subsequently we present computational results obtained on a set of realistic test instances of various sizes. In contrast to previous MINLP formulations, our MILP formulations can be solved in a reasonable amount of time even for large DESSSP instances. Furthermore, the results suggest that the approximation error in the technologies' performance models is well controllable by means of the triangulation granularity and the obtained energy systems are structurally similar to those synthesized using a MINLP formulation.

## ■ WB-05

Wednesday, 11:00-12:30 - Hörsaal 4

### Behavioral Operations Management (i)

Stream: Game Theory and Experimental Economics

Chair: *Anna-Lena Sachs*

#### 1 - How Negotiations Improve Performance in the Buyback Contract

*Michael Becker-Peth, Elena Katok, Ulrich Thonemann*

Human decision makers do not order optimally under the buyback contract and therefore full channel efficiency is not achieved. Previous experimental studies used an ultimatum offer setting, i.e., the supplier makes a take-it-or-leave-it offer to the retailer who places an order quantity and only the retailer was a human decision maker. We extend the literature in two ways: First, we use a human-human design as a baseline, having a human supplier offering a contract to a human retailer who decides on the order quantity. Second, we introduce a negotiation phase, where retailers and suppliers can offer contracts to the other party and accept other's offer at any time. If no agreement is made after a certain time, the supplier makes an ultimatum offer and the retailer places an order quantity. Firstly, our experimental results show that the overall SC efficiency in the human-human ultimatum game is below the single decision maker setting (0.69). This is due to suboptimal contract proposals (0.82) and suboptimal retailer rejections and order quantities. The efficiency loss accounted to the retailer is comparable to previous single decision maker studies. Secondly, we show that introducing an upfront negotiation phase increases SC efficiency significantly to overall 0.82. This is due to the periods where subjects agreed on a contract in the negotiation phase (0.97). Mainly the retailer benefits from the efficiency gains; the supplier's profit is comparable to the ultimatum treatment. The profit split in the negotiated agreements is fairly equal (54% vs 46%). If no agreement is made, ultimatum offers are comparable between the two treatments, but retailer request higher profits to accept the offer. Finally, we analyze the drivers of successful negotiations.

#### 2 - Diagnostic Accuracy in Congested Environments

*Mirko Kremer, Francis de Vericourt*

We investigate decision-making and judgments in the context of diagnostic services. As an example, consider a triage nurse who orders diagnostic tests and makes diagnoses for patients. Accumulating information by running additional tests on a patient is likely to improve the diagnosis, and diagnostic accuracy affects the value of the service provided. However, additional tests take time and thus increase congestion in the system. The service provider (e.g., a nurse) thus needs

to weigh the benefit of running an additional test against the cost of delaying the provision of services to others.

For systems without congestion, diagnostic accuracy has been well explored in the literature on sequential hypothesis testing, both theoretically and empirically. This paper investigates the effect of congestion on diagnostic accuracy. We conduct controlled laboratory experiments to test the predictions of a formal sequential testing model that captures the key trade-off between accuracy and congestion in the context described above.

#### 3 - Inventory decisions in retailing: A field experiment

*Anna-Lena Sachs, Michael Becker-Peth, Stefan Minner, Ulrich Thonemann*

Inventory management in retailing is a challenging task. Retail managers have to determine order quantities for many products every day. On the one hand, they aim to achieve a high product availability in order to attract many customers to their stores. On the other hand, they aim to minimize leftover inventories that would result in inventory holding costs or waste. The task of balancing supply and demand is especially challenging for perishable products with short shelf lives.

We investigate how to support retail managers best when making this challenging decision for newsvendor type products. To achieve this, we conducted a field experiment at a large European retail chain. We randomly assigned stores of the chain to several groups and provided different levels of information to the retail managers of each group for breads, rolls and pastries. The level of information ranged from sales data as it is readily available from standard point-of-sale scanner systems to the calculation of optimal order quantities.

Our findings reveal that giving additional information such as demand estimates in addition to sales data significantly improves order decisions. However, providing the highest level of information by making suggestions based on optimal order quantities does not always result in optimal decision-making. Many retail managers decide to deviate from the order quantity suggestions. We analyze the performance of the retail managers over several weeks. By comparing their decisions to the optimal order quantities, we investigate when decision makers deviate from the optimal solutions.

## ■ WB-06

Wednesday, 11:00-12:30 - Hörsaal 5

### Business Track 1

Stream: Business Track

Chair: *Marco Lübbecke*

#### 1 - E2E NetSim: Daimler Trucks' Approach Using OPTANO to Manage the Global Powertrain Network

*Thomas Schmall*

This talk presents the recent challenge of managing Daimler Trucks' global powertrain network at the tactical level. The goal of the project is to shift from local factory planning to centralized network planning. Challenges include data integration of master data and live data from different mainframe data sources, particularly SAP. A linear network model with hierarchical optimization is chosen to match the management target picture. It is integrated in a user friendly planning software and is able to cover operational details such as weekly time periods, inventory and transit times.

#### 2 - End-to-end value-based supply chain optimization at Aurubis

*Bianca Springub*

Aurubis is one of the leading copper producers and the world's largest copper recycler. Our core business is the production of marketable copper cathodes from copper concentrates, copper scrap and recycling raw materials. In order to manage the associated supply chain complexity, Aurubis decided to introduce an end-to-end value-based optimization tool that supports purchasing and production planning decisions. We give an overview how Aurubis modeled its supply chain incorporating technical restrictions, market restrictions and all relevant financial terms. We will highlight the key success factors that ensured a successful implementation in Aurubis' supply chain organization.



### 3 - Detecting location routing problems in geomarketing, sales force optimisation and task planning; specific challenges of real-life instances

Werner Heid

When companies attempt to optimise their sales force and task planning many decisions have to be taken and related operations must be carried out. Wrong decisions generally result in high costs and competitive disadvantages. High quality solutions allow the sales representatives to spend less time on the roads and more time with the customers. Professional applications for supporting decision-making in practice need to meet a wide range of different requirements: - Sales and delivery areas must be optimised. Desired results are characterised by geographically compact areas that are equally balanced regarding e.g. turnover potential or workload. - Solutions have to provide daily and weekly visit schedules for the planning period and exact visit sequences taking into account all relevant restrictions and customer specifications. - Alternative scenarios must be assessable in cases of business expansion and consolidation. - All results are based on reliable travel time and distance calculations. My presentation examines the specific location routing aspects in this target system. The range of related problems comprises different types and characteristics of location routing problems, e.g. periodic problems or multiple objectives. Successful algorithmic approaches have to cope with these conditions. The talk provides an evaluation of our applied methods based on their typical behavior, observed strengths and weaknesses in day-to-day business.

### 4 - State-of-the-art in industrial application of discrete-event simulation

Sven Spieckermann

Discrete-event simulation is an operations research method, which is widely accepted in industrial practice with a variety of applications. The presentation gives an overview of the state of simulation applications in production and logistics and considers the extent of the simulated systems (entire factory sites, supply chain) as well as different sectors (automotive, chemical industry, intralogistics, shipbuilding). The importance of different simulation tools and current trends in the tool development will be discussed. We will also describe the interplay of simulation and optimization in practical applications. Finally, the presentation illustrates the importance of the provision of a broad theoretical foundation with basics in computer science, operations research and statistics for the professional use of simulation in practice.

## ■ WB-07

Wednesday, 11:00-12:30 - Hörsaal 6

### Bilevel Network Games and Online Optimization (i)

Stream: Game Theory and Experimental Economics

Chair: Jannik Matuschke

#### 1 - Improvements on Online Machine Minimization

Kevin Schewior, Lin Chen, Nicole Megow

We consider the problem of online machine minimization in which jobs with hard deadlines arrive online over time at their release dates. The task is to determine a feasible preemptive schedule on a minimum number of machines. It was open whether an  $O(1)$ -competitive algorithm exists, even when the number of machine the optimum uses is a known constant  $m > 1$ . We settle this question in the two settings where jobs can be migrated among machines and where they cannot: If migration is allowed, there exists an  $O(\log m)$ -competitive algorithm for arbitrary  $m$  (SODA 2016). If migration is however not allowed, we provide a strong lower bound, showing that there exists no  $f(m)$ -competitive algorithm for any function  $f$  (SPAA 2016). Considering special cases, for instance, with respect to the structure induced by the jobs' intervals, we present algorithms for both settings that improve upon the general upper and lower bound, respectively.

#### 2 - Approximation Algorithms for Interdiction Problems

Stephen Chestnut, Rico Zenklusen

Interdiction problems ask about the worst-case impact of a limited attack on an underlying optimization problem. For example, the network

flow interdiction problem asks: how small can one make the maximum  $s$ - $t$  flow in a graph upon removing any  $k$  edges?

This talk starts at the 2003 pseudo-approximation algorithm for network flow interdiction by Burch et al., which returns either a 2-approximation or a super-optimal but infeasible solution within twice the budget. First, we will see that similar methodology can be applied to a whole host of other interdiction problems. Second, we will revisit network flow interdiction and discover that finding a true approximation, that is one that always respects the budget, is really hard. To this end, I will describe an approximation hardness theorem for network flow interdiction and then produce the first true approximation algorithm.

### 3 - Re-routing network flows in case of link failures

Jannik Matuschke, Thomas S. McCormick, Gianpaolo Oriolo

We introduce and investigate a version of network flows that can be re-routed when links in the network fail. Given a capacitated network with a dedicated source and sink, a flow on source-sink-paths is re-routable if after failure of an arbitrary arc in the network, we can re-route the interrupted flow from the starting point of the failing arc to the sink only using residual capacities in the remaining network. We distinguish two variants, depending on the definition of residual capacities: For a strongly re-routable flow, the re-routing can only use capacities that have not been used at all by the original nominal flow. For a weakly re-routable flow, we can additionally use all capacity used by flow that traversed the failing arc before.

We show that a strongly re-routable flow of maximum value can be found using a compact LP formulation, whereas the problem of finding a maximum weakly re-routable flow is NP-hard in general, even when all capacities are 1 and 2. However, for the case of unit capacities, we can show that every weakly re-routable flow can be transformed into a strongly re-routable flow. We also devise a surprisingly simple combinatorial algorithm that decides whether we can send a unit-value weakly re-routable flow. A consequence of this algorithm is that if the answer is yes, there always exists a half-integral solution. In contrast, re-routable flows of value larger than 1 can be arbitrarily fractional.

## ■ WB-08

Wednesday, 11:00-12:30 - Seminarraum 101/103

### GOR Master Thesis Prize

Stream: Prize Awards

Chair: Stefan Ruzika

#### 1 - Beyond the chaos: How to store items in the warehouse of an online retailer

Felix Weidinger

Scattered storage is a storage assignment strategy where units loads are purposefully broken down into single items, which are distributed all around the warehouse. This way, the probability of always having some item per SKU close-by is increased, which is intended to reduce the unproductive walking time during order picking. Scattered storage is especially suited if each order line demands just a few items, so that it is mainly applied by B2C online retailers. In this talk a storage assignment problem supporting the scattered storage strategy is formulated. We provide suited solution procedures and investigate important managerial aspects, such as the frequency with which refilling the shelves should be executed.

#### 2 - Compact MIP Models for the Resource-Constrained Project Scheduling Problem

Alexander Tesch

In the Resource-Constrained Project Scheduling Problem (RCPSPP) a set of jobs is scheduled non-preemptively subject to multidimensional resource and precedence constraints. The objective is to minimize the project duration (makespan). Most common Mixed-Integer-Programming (MIP) formulations for the RCPSPP are based on a discretization of the planning horizon. For large time horizons the size of such time-discrete models becomes computationally intractable. In this case, one would like to have alternative formulations that are time-independent. This talk investigates compact MIP models for the RCPSPP whose size is strongly polynomial in the number of jobs. In addition to two improved compact models from the literature we present



a new compact model. One substantial result is that all three compact models are equivalent by successive linear transformations, some of which are even unimodular. For their LP-relaxations, however, equivalence does not hold in general and we deduce a complete inclusion hierarchy under these transformations. It turns out that our new model supersedes the previous compact models in terms of polyhedral strength. Furthermore, we reveal that the time-indexed model is obtained from the new compact model by subsequent expansion and projection. Since the LP-relaxations of the compact models are weak in general, we further propose a linear programming extension. On this extension we characterize a class of strong cutting planes which generalize many previously introduced cuts from the literature. Our computational experiments show that the cutting plane approach greatly improves the solution quality of the compact models, that are finally compared to the classical time-indexed model.

### 3 - Integrated Location-Inventory Optimization in Spare Parts Networks

Patrick Zech

This Master's thesis is concerned with integrated location-inventory optimization in spare parts networks. A semi-Markov decision process (SMDP) is developed, formulated as linear programming (LP) model and finally, embedded into a set-covering problem framework. The resulting model is a mixed integer linear program (MILP) which integrates (1) strategic facility choice, (2) tactical base-stock level setting and (3) operational sourcing decisions. The three-layered decision model exploits the potential benefits associated with pooling inventory physically or sharing inventory virtually among multiple facilities during the design phase of a supply chain network. Due to the model's special structure and its linearity, Benders' decomposition (BD) is applied to solve the problem. Several valid inequalities are added to the master problem in order to expedite convergence of the BD algorithm. Furthermore, we address the issue of combinatorial complexity inherent in large-scale SMDPs and thus, propose an exact method to effectively reduce the SMDP state space in each BD iteration. Numerical experiments confirm the efficiency of BD in comparison to the brute-force approach branch and bound (BB). Furthermore, experimental results emphasize the value of the integrated MILP compared to the sequential 'location first, inventory and sourcing second' approach. The cost savings are particularly high in networks with low fixed facility location cost, high shipment cost and high demand rates as virtual inventory sharing opportunities increase in these cases.

### ■ WB-09

Wednesday, 11:00-12:30 - Seminarraum 105

#### Finance I

Stream: Finance

Chair: Marcus Brandenburg

#### 1 - IPOs, the Level of Private Equity Engagement and Stock Performance Matters: Empirical Evidence from Germany

Tim Herberger, Andreas Oehler, Matthias Horn, Henrik Schalkowski

We extend the existing IPO literature by focusing on stock performance matters combined with companies' ownership structures and, in particular private equity ownerships capital engagement, for the first time. The unique dataset on German IPOs from 2004 to 2014 allows us to identify companies' ownership structures before and after the IPO. We address on mainly two questions in our work. First, do companies that were (partially) owned by private equity investors prior the IPO show lower short-term stock returns after the IPO than companies without prior investments of private equity investors? Second, is the companies' long-term stock performance after the IPO better when private equity investors' involvement is higher at the IPO? We find that the level of private equity investors' shareholding prior the IPO predicts future returns, particularly in the longer run. Furthermore, we document that the stronger the private equity investors reduce their engagement the stronger is the performance of the issued stock. Our findings are robust to IPOs' industrial sectors.

#### 2 - The Impact of Central Clearing on Credit Default Swap Spreads - Evidence from the North American and European Corporate Credit Default Swap Market

Benjamin Hartl, Andreas Oehler

We contribute to the emerging debate on the joint dynamics of the markets for Credit Default Swaps (CDSs) and the central clearing functions of Central Counterparties (CCPs) by using a unique dataset of 155 North American and 151 European corporate single name CDSs for the period from late 2009 to early 2014. By applying three different analytical methods, we find that CDS spreads increase around the commencement of central clearing. We argue that the spreads' increase is due to higher transaction costs and a reduction in counterparty risk, which in turn increases the values of the underlying contracts.

### 3 - A longitudinal DEA study on financial performance evolutions in the automotive supply chain

Marcus Brandenburg

A data envelopment analysis (DEA) is presented to assess financial performance evolutions in the automotive supply chain. A sample of 33 decision-making units (DMUs), 17 globally operating automotive manufacturers and 16 suppliers, is in focus of this analysis in which cost levels and capital requirements are put into relation to sales volume and profitability. Cost of goods sold, operating capital and net fixed assets represent the financial input of a company while sales and earnings before interest and taxes (EBIT) reflect the financial output. The financial performance of a firm is indicated by its efficiency, calculated by an input-oriented variable returns to scale model.

In order to reveal performance evolutions over time, a longitudinal DEA approach is chosen that covers the years from 2003 and 2012. In order to assess the stability of relationships between performance leaders and followers over time, changes in the links between peer DMUs and follower DMUs and the strength of each link are assessed in a graph theory approach. A multiple linear regression analysis reveals which operational performance factors are predictors of financial performance. In this context, geographical and structural specifics of different DMU groups, such as performance differences between European, Asian and US companies or between original equipment manufacturers (OEMs) and suppliers, are taken into account.

### ■ WB-10

Wednesday, 11:00-12:30 - Seminarraum 108

#### Flexibility in Revenue Management

Stream: Pricing and Revenue Management

Chair: Jochen Gönsch

#### 1 - Implications of Strategic Customer Choice for Revenue Management with Flexible Products

Sebastian Vock, Catherine Cleophas, Natalia Kliewer

Flexible products offer a way to handle uncertain demand while still implementing successful revenue management. Generally, the underlying models assume myopic customer choice. However, websites such as betterbidding.com or biddingtraveler.com suggest that increasingly, customers approach even flexible products strategically. Therefore, customers' expectations about the actual manifestation of a flexible product can diminish revenue benefits.

Our research formalizes and evaluates a model of strategic customer preferential choice with regard to flexible products' manifestations. We show that randomly allocating flexible products to manifestations can help to counteract strategic behavior. Our results demonstrate that strategic customers can significantly reduce the revenue gains otherwise attainable through flexible products, depending on the reliability of customers' expectations and on customers' risk-affinity.

#### 2 - Overbooking in network revenue management with supply-side substitution

Sebastian Koch, Jochen Gönsch, Claudius Steinhardt, Robert Klein

In this talk, we consider the combined overbooking and choice-based capacity control problem in the presence of supply-side substitution. The problem is briefly summarized as follows: As a result of price discrimination, a firm offers a variety of differently priced products over a booking horizon. Customers arrive successively and stochastically over time with each customer purchasing at most one unit of a product. Within the booking horizon, the firm can continuously adjust the availability of the products by means of capacity control. Service provision takes place after the booking horizon, using several substitutable

resources. However, if reservations cannot be fulfilled with the available resources, denied boarding penalties are incurred. Thus, the subsequent decision problem is to minimize the overbooking costs. The above joint capacity control and overbooking problem is particularly relevant for the car rental industry, where the products are provided using a number of substitutable car types. Denied boarding penalties are incurred, for example, if cars must be transferred to the rental station or customers must be denied. We model the problem as a stochastic dynamic program, using a recursively formulated value function. However, an exact solution is not possible for realistic problem sizes due to the multi-dimensional state space. Therefore, we suggest heuristic approaches using extensions of the well-known choice-based deterministic linear program as well as approximate dynamic programming techniques. We conduct a number of computational experiments to investigate the performance of the proposed approaches.

## ■ WB-11

Wednesday, 11:00-12:30 - Seminarraum 110

### Managing Inventory Systems

Stream: Production and Operations Management

Chair: Yanwen Dong

#### 1 - Optimizing Machine Spare Parts Inventory Using Condition Monitoring Data

Sonja Dreyer, Jens Passlick, Daniel Olivotti, Benedikt Lebek, Michael H. Breitner

In the manufacturing industry, storing spare parts means capital commitment. Therefore, reducing the spare parts inventory is a real problem in the field. Especially in the case of large machines with numerous components or complete machine parks, a precise determination of the necessary spare parts is a major challenge. In addition, the complexity of determining the optimal amount of spare parts increases when using the same type of component in different machines. To find the optimal spare parts inventory, the right balance between storage costs and the risk of machine down times has to be found. Several factors are influencing the optimum quantity of stored spare parts including the failure probability, the delivery times of the spare parts, storage costs, the costs of machine down times and the necessary machine availability. Therefore, an optimization model addressing the explained requirements is developed with the purpose of being easy to use in practice. Determining the failure probability of a machine component or an entire machine is a key aspect when optimizing the spare parts inventory. By means of condition monitoring the uncertainty of determining this failure probability is reduced decisively. Condition monitoring leads to a better assessment of the component's failure probability. This results in a more precise forecast of the optimum spare parts inventory according to the actual condition of the respective component. Therefore, data from condition monitoring processes play an important role in the developed optimization model.

#### 2 - Managing an Integrated Production and Inventory System Selling to a Dual Channel: Long-Term and Walk-In Markets

Mohsen Elhafsi, Essia Hamouda

We consider a manufacturer making and selling a single product to long-term and walk-in markets. The manufacturer's objective is to coordinate pricing, production scheduling and inventory allocation decisions in a dynamic setting. Demand for the product fluctuates due to varying state of the world conditions which we describe through a finite state Markov chain. Orders from both markets arrive continuously over time one unit at a time with stochastic inter-arrival times. Walk-in demand materializes according to an independent homogenous Poisson process while long-term demand materializes according to a k-stage Erlang distribution. Units are produced one at a time in a make-to-stock fashion in anticipation of future demands with stochastic production times. If an order is fulfilled, the manufacturer instantly collects the sales revenue. However, if an order cannot be fulfilled immediately, the manufacturer incurs a backorder cost penalty if the order is from the long-term market otherwise the sale is lost if it is from the walk-in market. We formulate the problem as a Markov decision process and characterize the structure of the optimal policy. We show that the optimal policy, in addition to specifying the optimal walk-in market sale price, is characterized by two state-dependent thresholds, one specifies how to allocate inventory among the two markets and the other specifies how to schedule production. We also treat the special cases of

static and state of the world dependent walk-in market pricing as well as the case of a spot market where the price is exogenously set. Finally, through numerical experiments, we offer managerial insights.

### 3 - An Investigation of General Aptitude Test Battery in Relation to Cell Production Efficiency

Yanwen Dong

As major studies have put their emphasis on technical factors of cell production systems, there is a singular absence of articles of investigating the impact of human factors on production cells. We have made a series of experimental studies to investigate the impact of human factors. According to our previous studies, both the experience (learning effect) and workers have significant impacts on the productivity of production cells, the impact of the experience and workers on the productivity are 19.63% and 67.01% respectively. As two-thirds of variance of the assembly times was decided by workers, workers' aptitude has stronger impact on the productivity than the experience. It is very important to measure the workers' aptitude in order to assign the right workers in the right place. In this paper, we improve our previous research and make an investigation into the relation between workers' scores of the General Aptitude Test Battery (GATB) and cell production efficiency. We put our emphasis on developing an effective tool to measure the workers' aptitude toward to cell production and making the following contributions: (1) Different from most of previous researches that most of them applied questionnaire survey or case study methods, this paper apply the experimental study method. We design and conduct a cell production experiment and use the operation time to measure productivity of production cells quantitatively. (2) In order to find the workers' aptitude that closely related to cell production efficiency, we administer GATB, to the workers and measure their nine work-related abilities. (3) We apply the regression analysis method to examine the relationship between the workers' scores of GATB and cell production efficiency.

## ■ WB-12

Wednesday, 11:00-12:30 - Seminarraum 202

### New Approaches

Stream: Metaheuristics

Chair: Stefan Voss

#### 1 - Multi-agent stochastic diffusion search algorithm for optimization problems

Mümin Emre Şenol, Adil Baykasoğlu

Although the nature of the optimization problems is usually varying they are generally modelled as static problems. One of the reasons behind this may be related to the difficulty in devising dynamic optimization algorithms by making use of the classical structured programming/modelling approaches. Another interesting observation is related to the realization of the metaheuristic algorithms; although the natural phenomenon where the analogy is made is usually dynamic and varying these algorithm's internal structures are actually static. In this research we try to implement a metaheuristic algorithm which is known as Stochastic Diffusion Search (SDS) as a truly dynamic optimization algorithm by making use of the multi-agent modelling and programming approach. In the proposed SDS algorithm solution vectors (agents) can communicate with each other for search direction determination, they can decide to disappear; new agents can appear (so the population size is not fixed) etc. In other words, the proposed algorithm has an inherent dynamic structure so it can be more easily adapted to dynamic optimization problems. The proposed algorithm is developed in JACK multi-agent development environment. Several optimization problems like single machine scheduling, project scheduling are modelled as solved, preliminary results are very encouraging.

#### 2 - A nature-inspired approach for addressing large-scale optimization problems

Eduardo Lalla-Ruiz, Eduardo Segredo, Stefan Voss, Emma Hart, Ben Paechter

Nature-inspired algorithms have been extensively used for tackling optimisation problems. Some of these approaches have been successfully used for addressing well-known combinatorial problems such as the quadratic assignment problem, knapsack problems, machine scheduling, among others. In this work, we present a novel algorithmic adaptation to continuous optimization of a recently proposed population-based meta-heuristic based on the collective behavior of migrating

birds. In doing so, we also propose a new operator to suitably generate neighbor solutions in a continuous decision space. The computational experimentation provided in this work relies on a set of well-known large-scale continuous problems. The experimental evaluation indicates that our proposal is able to improve, for some cases, those results obtained by one of the best approaches proposed in the literature.

## ■ WB-13

Wednesday, 11:00-12:30 - Seminarraum 204

### Multiobjective Linear Optimization I

Stream: Control Theory and Continuous Optimization

Chair: *Andreas Löhne*

#### 1 - Solving bilevel optimization problems being polyhedral on the lower level

*Alexandra Rittmann, Andreas Löhne*

It is well-known [Fülöp, 1991] that linear bilevel optimization problems can be solved by optimizing the upper level objective function over the set of Pareto-optimal extremal points of a corresponding multiple objective linear program. We extend this result to more general upper level functions and discuss improvements resulting from a more direct approach based on polyhedral projection. It is shown how solver software for both multiple objective linear programming and polyhedral projection can be used to solve bilevel optimization problems being polyhedral on the lower level. By slight modifications of these solvers we can implement efficiently branch-and-bound techniques known from global optimization. Numerical examples are given.

#### 2 - A nonsmooth Newton method for disjunctive optimization problems

*Stephan Buetikofer, Diethard Klatte*

In previous works of the authors [1,2] a nonsmooth Newton method was developed in an abstract framework and applied to certain finite dimensional optimization problems with C1,1 data. Such problems arise e.g. from general semi-infinite optimization problems (GSIP) under suitable assumptions. We will explain how we apply this method to disjunctive optimization problems. For this we reformulate stationary points of a disjunctive optimization problem [3] as a zero of a suited nonsmooth function  $F$ . We will work out in detail the concrete Newton schemes from [1,2] for disjunctive optimization problems and discuss the (local) convergence properties of the Newton scheme.

##### References

[1] S. Buetikofer, Globalizing a nonsmooth Newton method via non-monotone path search, *Mathematical Methods of Operations Research* 68 No. 2, (2008) 235 - 256

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[3] H.T. Jongen, J.J. Rückmann, O. Stein, Disjunctive Optimization: Critical Point Theory, *JOTA* 93 No.2, (1997) 321-336

#### 3 - Problems being equivalent to multiple objective linear programming

*Andreas Löhne*

The problem to project a polyhedral convex set into a subspace is equivalent to a multiple objective linear program. This result is used to show that the following problem classes can be solved via multiple objective linear programming: parametric linear programming, parametric multiple objective linear programming, multiple objective linear programming with arbitrary polyhedral convex ordering cone (vector linear programming), vertex enumeration, calculus for polyhedral convex functions. Corresponding modelling techniques are discussed and numerical examples are presented.

## ■ WB-14

Wednesday, 11:00-12:30 - Seminarraum 206

### Complexity in Multiobjective Combinatorial Optimization

Stream: Decision Theory and Multiple Criteria Decision Making

Chair: *Michael Stiglmayr*

#### 1 - Output-sensitive Complexity of Multiobjective Combinatorial Optimization

*Fritz Bökler, Matthias Ehrgott, Christopher Morris, Petra Mutzel*

We study output-sensitive algorithms and complexity for multiobjective combinatorial optimization (MOCO) problems. In this computational complexity framework, an algorithm for a general enumeration problem is regarded efficient if it is output-sensitive, i.e., its running time is bounded by a polynomial in the input and the output size. We provide both practical examples of MOCO problems for which such an efficient algorithm exists as well as problems for which no efficient algorithm exists under mild complexity theoretic assumptions.

#### 2 - Toward a categorization of tractable multiobjective combinatorial optimization problems

*Michael Stiglmayr*

It is a well known fact that multiobjective combinatorial optimization problems are not efficiently solvable in general. This is true for two reasons. First, from an asymptotic worst case perspective, the number of nondominated points may grow exponentially with the input size. Second, the computation of nonsupported efficient solutions may be significantly more demanding than the solution of the single objective analogon. Linear scalarization methods capable of yielding nonsupported efficient solutions introduce new (knapsack-type) constraints to the combinatorial structure. Thus, these scalarized problems lead to resource constrained versions of combinatorial problems with the consequence that these scalarized single objective combinatorial optimization problems turn out to be NP-hard. Apart from this general observation, are there also variants or cases of multiobjective combinatorial optimization problems which are easy and, if so, what causes them to be easy? In this talk, we address these two questions and give a systematic description of reasons for easiness.

The results are based on a collaboration with José Rui Figueira, Carlos Fonseca, Pascal Halffmann, Kathrin Klamroth, Luís Paquete, Stefan Ruzika, Britta Schulze, and David Willems in the framework of the DAAD project tractability in multiobjective combinatorial optimization.

#### 3 - Supported Efficient Solutions for Unconstrained Binary Multiobjective Optimization Problems, Arrangements of Hyperplanes and Zonotopes

*Britta Schulze, Kathrin Klamroth, Michael Stiglmayr*

The weighted sum scalarization is an important tool for computing the set of supported efficient solutions of multiobjective optimization problems. We consider a particularly simple class of unconstrained binary optimization problems with  $m$  objective functions (UBMOP) having some positive and some negative cost coefficients. In this case, there is a one to one correspondence between (1) the extreme supported solutions of UBMOP, (2) a weight space decomposition, (3) the cells of an associated arrangement of hyperplanes, and (4) the nondominated extreme points of a corresponding zonotope. While the interrelation between (1) and (2) holds for general MOCO problems, (3) and (4) rely on the special structure of UBMOP. We take advantage of these relations for efficiently computing the set of extreme supported solutions. As a side effect, nonextreme supported solutions can easily be identified in the arrangement of hyperplanes.

## ■ WB-15

Wednesday, 11:00-12:30 - Seminarraum 305

### Project Scheduling Applications (i)

Stream: Project Management and Scheduling

Chair: *Norbert Trautmann*

**1 - Scheduling of complex dismantling projects in nuclear facilities**

*Felix Huebner, Rebekka Volk, Frank Schultmann*

The International Energy Agency (IEA) expects that until 2040 about 200 nuclear reactors in various nuclear facilities worldwide have to be decommissioned and dismantled. Dismantling of nuclear facilities is a large-scale project with high requirements for safety and security, an expected makespan about 15 to 20 years and budget with about 0.5 to 1 billion Euros per facility. Project planning is based on very few experience values and thus various uncertainties exist. The scheduling of dismantling activities for nuclear facilities imposes high requirements and has to incorporate uncertainties. Therefore, we develop a decision making model that provides a calculation of a reliable dismantling plan with minimal total project costs. The model includes three steps: 1. simulation of different scenarios, 2. calculation of a cost-optimal schedule (MRCPSPP with precedence constraints) for every simulated scenario, 3. identification of robust solutions. In the simulation of scenarios we consider different execution sequences and different durations of activities. The calculation of a cost-optimal schedule is based on a relaxation-based enumeration approach. First, we solve the optimization problem without resource restrictions. Then, we examine the resulting schedule for renewable or cumulative resources conflicts. If such a conflict exists, we introduce further appropriate precedence relations. The created enumeration tree represents every feasible schedule. To find the optimal schedule we use a branch-and-bound algorithm which eliminates certain parts of the enumeration tree by using upper and lower bounds (total costs). All calculated schedules are evaluated via robustness criteria to find a robust schedule.

**2 - An application of Microsoft Excel's Evolutionary Solver to the RCPSP**

*Norbert Trautmann, Mario Gnägi*

The Solver Add-In of Microsoft Excel is widely used in courses on Operations Research and in industrial applications. Since the 2010 version of Microsoft Excel, in addition to the Simplex algorithm for linear programming, the GRG algorithm for nonlinear programming, and a Branch-and-Bound algorithm for mixed-integer programming, the Solver Add-in comprises a so-called evolutionary solver. We analyze how this metaheuristic can be applied to the resource-constrained project scheduling problem RCPSP. We present an implementation of a schedule-generation scheme in a spreadsheet, which we combine with the evolutionary solver for devising feasible schedules. Our computational results indicate that this approach performs surprisingly well for 360 non-trivial instances of the J30 PPSLIB set.

**■ WB-16**

*Wednesday, 11:00-12:30 - Seminarraum 308*

**Simulation in Health Care**

**Stream: Health Care Management**

*Chair: Sebastian Rachuba*

**1 - Reallocation of operating hours in an operating theatre**

*Lisa Koppka, Matthias Schacht, Lara Wiesche, Khairun Bapumia, Brigitte Werners*

Operating room planning is highly restricted by a variety of conditions. Regardless of the planning method, adjustments in those conditions result in major consequences. Due to budget and personnel restrictions, expansion of the limiting factors is often difficult to realize. Therefore, we address shifting instead of resizing of capacities. In particular, we aim at allocating the total operating room time over the available operating rooms. While the total amount of available time in the operating theatre remains the same, we modify the individual opening hours taking the specialization of rooms into account. To depict the planning procedure authentically, we consider realistic patient data and analyze them with regard to treatment duration, type of surgery and frequency of occurrence. Different configuration alternatives are included in an optimization model to generate schedules, which are analyzed using a simulation model. Uncertainty in treatment duration is embedded in the simulation model through distributions fitting realistic data. The results indicate impacts on objectives such as overtime hours, short-term rescheduling of patients and the operating room utilization and provide support for decision makers.

**2 - An Integrated Operating Room Scheduling and Patient Pick-up and Drop-off Problem**

*Lars Moench, Hanna Ewen*

This research is motivated by a real-world operating room (OR) scheduling problem found in a private German Eye Hospital. An integrated appointment scheduling and vehicle routing problem is studied since minibuses are operated by the eye hospital to pick-up the patients at their home and bring them to the hospital and transport them after their surgeries to their homes. A Non-dominated Sorting Genetic Algorithm (NSGA)-II scheme based on the random key representation is proposed to compute appointment times for the patients. Based on these times, the patients are assigned according to different criteria to groups that are routed together. Since each patient can be either a linehaul or a backhaul customer, a series of vehicle routing problems with mixed linehauls and backhauls (VRPMBs) is considered where the hospital serves as the depot. The resulting VRPMB instances are solved using the record-to-record travel heuristic from the VRPH library. We are interested in reducing the waiting time of the patients, increasing the utilization of the operating rooms, and reducing the cost for the pick-up and drop-off service of the hospital, respectively. Discrete-event simulation is used to calculate the fitness function values in the NSGA-II approach taking into account the availability of the staff and the stochastic surgery times. Results of extensive computational experiments are presented to demonstrate that the proposed heuristic works well.

**3 - A generic simulation based DSS to evaluate patient transfer decisions strategies in hospital ward clusters**

*Thomas Stoeck, Taieb Mellouli*

Today 30% off all German hospitals are unprofitable. In order to lower costs and to handle the estimated increase of patient admissions, all hospitals have to increase their efficiency. Managing inpatient beds, which are one of the most expensive resources in hospitals, is crucial. Without idle beds available waiting times occur, operations have to be cancelled or patients have to be rejected. Simulation studies show that increasing the flexible use of beds by creating ward cluster can reduce shortages up to 95% within a year. A cluster is defined as a class of wards where patients can be admitted if the proper ward has no idle bed capacities. To prevent disadvantages like long travel distance for staff or creating new bottlenecks on other wards good transfer decision strategies are needed. Based on a classification of possible transfers regarding range and dimensionality deterministic and stochastic criteria for these strategies are analyzed by simulating given cluster scenarios. Technical compliance and physical distance of the wards are examples of deterministic criteria while the estimated amount of patients and their length of stay are examples for stochastic criteria. It is expected that these criteria will affect the rating of the cluster scenarios. In order to evaluate transfer decision strategies based on these criteria we discuss a possible enhancement of our generic simulation model facing the complexity of hospital-wide relocation processes. Our approach is based on a combination of discrete event simulation and optimization techniques like stochastic programming or linear programming. By using standardized real world data of a hospital we are able to receive practical relevant results and furthermore our approach can easily be reused in other hospitals.

**4 - Simulating pathway redesign at an NHS walk-in centre**

*Sebastian Rachuba, Martin Pitt*

Walk-in centres across the UK provide a wide range of services for patients arriving without an appointment. According to patient conditions, an assessment of medical history is required and tests may need to be performed before a decision on treatment and further management of the patient is made. As individually required care is often not known in advance, a well-balanced skill set across members of clinical staff is essential to provide care both effectively and efficiently. In our study, we focus on a genitourinary medicine clinic in the South West of England as an example for an NHS walk-in centre. The clinic offers both appointment and walk-in sessions and sees approximately 18,000 patients per year. In general, long wait times due to high patient numbers are compounded by bottlenecks accessing appropriately skilled staff and properly equipped rooms. Many patients require multiple services which often remains unknown until a patient is triaged or a clinical assessment takes place. Due to a high level of discretion, effective streamlining of symptomatic and asymptomatic patients is difficult. In order to improve waiting times for patients and to manage staff workload, changes to the existing pathways have been proposed, such as fast-tracking non-symptomatic patients and integrating existing services. A discrete event simulation model captures the current flow of

patients at the clinic taking into account available resources. We implement re-configurations in terms of different what-if scenarios and evaluate how the proposed changes impact key performance measures at the clinic. Based on these findings, we discuss how implementing these changes can be facilitated.

## ■ WB-17

Wednesday, 11:00-12:30 - Seminarraum 310

### Demand Fulfillment in Hierarchies

Stream: Supply Chain Management

Chair: *Herbert Meyr*

#### 1 - A deterministic approach for multi-period hierarchical demand fulfillment

*Jaime Cano Belmán, Herbert Meyr*

In Make-to-Stock environments with a hierarchical sales organization and heterogeneous customers (i.e. profit-based segmented customers) the optimal matching of available resources (in form of Available-to-Promise - ATP) with demand is a challenging task if resources are scarce. Demand Fulfillment in a first step allocates these scarce resources as quotas to forecasted demand. In a second step, these reserved quotas are consumed (promised) when actual customer orders arrive. In a multi-stage sales hierarchy, this allocation process often has to be executed level by level, on basis of decentral, aggregate information only. Decentral, deterministic linear and non-linear programming models are proposed approximating the first-best benchmark of a central, multi-period allocation planning with full information. Additionally, a model for real-time order promising will be described. A roll over simulation has been performed to obtain first insights into the model's behaviour.

#### 2 - Service-level based allocation planning in customer hierarchies

*Konstantin Kloos*

Meeting the explicit or implicit service level requirements of their customers is an important, but also very challenging, task for many companies. If some customer segments require higher service levels, allocated ATP approaches can help to reach the service requirements when supply is scarce. The determination of such allocations is crucial to the performance of the overall demand fulfillment system and determines the service level of all customers. No research has yet addressed the determination of these allocations under hierarchically structured customer groups. Our model tackles this allocation problem in a multi-period setting, where we measure service levels independently for each period. Based on this, we derive elementary properties of an optimal allocation and then extend the model to a setting, where service levels are not measured period-wise but - more realistically - over a sequence of periods. This allows adjusting period-wise service level targets based on actual demand realizations.

#### 3 - Decentralized allocation planning in customer hierarchies with stochastic demand

*Maryam Nouri Roozbahani, Moritz Fleischmann*

To maximize profits, given limited resources, companies commonly divide their overall customer base in different segments, based on their respective profitability. In many cases, these customer segments have a multi-level hierarchical structure, which reflects the structure of the sales organization. Demand fulfillment allocates available supply to these hierarchical segments. In this setting, transmitting all detailed information regarding base customer segments is not feasible in general. Therefore, decision makers on higher levels of the hierarchy need to make their allocation decisions based on aggregated information. This presentation reports on a research project that addresses demand fulfillment, given such hierarchically structured customer segments. The focus is on identifying critical information for good decentralized allocation decisions. To this end, Revenue Management concepts are applied.

## ■ WB-18

Wednesday, 11:00-12:30 - Seminarraum 401/402

### Location Routing

Stream: Logistics, Routing and Location Planning

Chair: *Michael Schneider*

#### 1 - A new approach for a location routing problem with pick-up and delivery including home delivery services for food products

*Christian Franz, Rainer Leisten*

Customers in western countries still mostly continue to shop their daily life products by going to supermarkets and other stores. In Germany, the online grocery sales market comprises just 0.2 percent of total grocery sales. However there are two systems for food delivery services in Germany: pure players (who operate exclusively online, i.e. with no offline stores) vs. store-based home delivery services of traditional large retailers. None of these systems has become widely successful so far. The reasons for this are diverse. A low confidence in food online services is one main reason. A more customer motivating approach might be combining the two concepts as follows. Customers order online and have the opportunity to determine from which store the products shall come from. To address this issue, we model the problem as a location routing problem (LRP) with pick-up and delivery. LRP takes into account vehicle routing aspects. In this case, the locations represent the parking positions for the cars of the delivery service company. The different stores and the customers are interpreted as pick-up and delivery points. Furthermore, our model includes aspects of time-windows as well as multi-product problems and we try to formulate this problem as a multi-criteria decision problem to consider the costs of the system and also the service level, including the freshness of food products. We present this model as a mixed-integer linear model and use CPLEX 12.6 to solve small-scale instances. Computational results show that instances with up to 30 points (parking positions, pick-up and delivery points) can be solved in reasonable computation time.

#### 2 - Strategic Planning of Electric Logistic Fleet Networks: A Robust Location Routing Approach

*Maximilian Schiffer, Grit Walther*

Climate change and increasing environmental awareness call for a change towards sustainable transportation networks. Within this context, electric commercial vehicles (ECVs) contribute significantly to lower greenhouse gas as well as noxious and noise emissions. However, recharging options on routes have to be provided to keep vehicles operational, since the driving range of ECVs is still limited. Thus, it is necessary to design optimal transportation networks for ECVs considering vehicle routing decisions as well as siting decisions for recharging stations simultaneously. Additionally, many uncertainties exist in this strategic decision, e.g. regarding future developments of customer locations, delivery requirements, and demand. Against this background, we derive the Robust Electric Location Routing Problem with Time Windows and Partial Recharging considering uncertainties in customer demand, time windows and customer locations. We present an adjustable robust counterpart (ARC) with a non-adjustable decision component (siting charging stations) and an adjustable decision component (routing of ECVs). Since even the underlying deterministic planning problem is NP-hard, the ARC is no longer computationally tractable for large instances, even if robust reformulation techniques are used. Thus, we present a hybrid of adaptive large neighborhood search, dynamic programming and local search to solve the ARC for large instances using an adversarial approach. The proposed solution method provides high quality results for the underlying problem. To highlight the benefit of the proposed modeling approach, results are compared to results of deterministic models regarding overall costs, vehicle fleet and number of charging stations.

#### 3 - A model to locate and supply biorefineries in large-scale multi-biomass supply chains

*Nasim Zandi Atashbar, Nacima Labadie, Christian Prins*

Increasing concerns about the effect of greenhouse gas emissions from fossil fuels and ever-growing energy demand have raised a strong interest in sustainable and renewable energies. Biofuels derived from biomass can play a crucial role as one of the main sources of renewable energies. As logistics may represent 50% of the biomass cost, it is necessary to design efficient biomass supply chains to provide biorefineries with adequate quantities of biomass at reasonable prices and appropriate times. The task is challenging since, contrary to industrial

logistics, the raw materials (oilseed and lignocellulosic crops) are produced slowly, seasonally, and with a limited yield, over vast territories. In particular, a refinery must use successive crops during the year, e.g., miscanthus (a kind of cane) in Spring, rape in July, cereal straws in August, camelina in October and short rotation trees like willows in Winter. The paper proposes a Mixed Integer Linear Program (MILP) to optimize a multi-period and multi-biomass supply chain for several bio-refineries, at the tactical decision level. The locations of refineries can be fixed by the user or determined by the model. The aim is to minimize the total cost of the supply chain, including biomass production, pretreatments (e.g., pelletization), storage, handling, bio-refineries setup and transportation, while satisfying given refinery demands in each period. The model determines the amount of biomass produced, shipped and stored during each period as well as the number, the size and the locations of bio-refineries. The resulting MILP is tested and validated on small instances, before solving a large-scale real case covering two regions of France (Champagne-Ardenne and Picardie) with 273 territorial units and 8 biomass types.

## ■ WB-19

Wednesday, 11:00-12:30 - Seminarraum 403

### Algorithm Engineering for Route Planning (i)

Stream: Traffic and Passenger Transportation

Chair: *Matthias Müller-Hannemann*

#### 1 - Customizable Contraction Hierarchies

*Ben Strasser, Julian Dibbelt, Dorothea Wagner*

We consider the problem of quickly computing shortest paths in weighted graphs. Often, this is achieved in two phases: 1) derive auxiliary data in an expensive preprocessing phase, 2) use this auxiliary data to speedup the query phase. By adding a fast weight-customization phase, we extend Contraction Hierarchies to support a three-phase workflow: The expensive preprocessing is split into a phase exploiting solely the unweighted topology of the graph, as well as a lightweight phase that adapts the auxiliary data to a specific weight. We achieve this by basing our Customizable Contraction Hierarchies on nested dissection orders.

#### 2 - How Far You Can Drive: Fast Exact Computation of Isocontours in Road Networks

*Moritz Baum, Thomas Bläsius, Valentin Buchhold, Julian Dibbelt, Andreas Gemsa, Ignaz Rutter, Dorothea Wagner, Franziska Wegner*

Electric vehicles play an increasingly important role in sustainable mobility. One of the main obstacles to a widespread adoption is range anxiety, that is, the fear of running out of power. Displaying the cruising range of an electric vehicle may alleviate range anxiety.

Driven by this application, we study the problem of computing isocontours in static and dynamic road networks, where the objective is to identify and visualize the boundary of the region that is reachable from a given source within a certain amount of time, or alternatively, with a certain battery charge. Although this problem has a wide range of other practical applications (e.g., urban planning, geomarketing), there has been little research on fast algorithms for large, realistic inputs, and existing approaches tend to compute more information than necessary.

We provide several easy-to-parallelize, scalable algorithmic approaches for faster computation of isocontours in road networks. To this end, we extend established speedup techniques for routing in road networks. For visualization, we propose isocontours represented by polygons that separate reachable and unreachable components of the network. We introduce several approaches that run in (almost) linear time and are simple enough to be implemented in practice. By extensive experimental evaluation, we demonstrate that our techniques enable accurate isocontour computations within milliseconds even on networks at continental scale, significantly faster than the state-of-the-art.

#### 3 - Recent Advances in Public Transport Timetable Information Systems

*Matthias Müller-Hannemann*

We survey the state-of-the-art in efficient algorithms for timetable information systems. Thereby, we discuss several problem settings, including versions of multi-criteria, robust, and real-time information. Recent years have shown significant progress in the field, but a number of challenges still remain from a practical point of view.

## ■ WB-20

Wednesday, 11:00-12:30 - Seminarraum 404

### Business and Industrial Analytics

Stream: Business Analytics and Forecasting

Chair: *Arnd Huchzermeier*

#### 1 - Demand volatility and skill-orientated workforce scheduling

*Matthias Schinner, Peter Letmathe*

Multiple research studies have shown that learning of shop-floor employees can significantly reduce production costs and also lead to improvements of product quality. The antipode of learning is forgetting referring to degrading competencies if the respective skills are not utilized over a longer period of time. Conventional scheduling methods often neglect competency development (degradation) and the consequences of task assignments to employees on long-term firm performance. We analyze learning-oriented task assignments to employees and different training strategies and their impacts on costs and skill levels of employees. Taking demand volatility into account, we present an MIP workforce scheduling model that considers learning and forgetting of employees. Furthermore the model incorporates skill development, knowledge depreciation, training measures and shortage costs. As a result we show how to generate learning and qualification strategies under different demand volatility scenarios and analyze the specific properties of our solutions.

#### 2 - Judgmental Demand Forecasting for Direct Sales: Segmenting by Type or Age

*Arnd Huchzermeier*

Manufacturers and retailers often face the challenge that they have to commit supply orders well ahead of the selling season. We consider the case of a German manufacturer selling premium mountain and road bikes online. All components are ordered ahead of the selling season, mostly from Asia. Moreover, more than half of the product collection is newly introduced each year. While most competitors have filed for bankruptcy, the company has exhibited an annual growth rate of 40% and is considered as technology, quality and cost leader in its industry. This case study shows how Sales & Operations Planning (S&OP) can be effectively optimized to improve supply chain performance.

#### 3 - Spare parts dispatch fraud detection analysis

*Shivangi Verma*

Along with warranty service abuse, dispatch frauds are a huge concern area for major IT hardware companies. A spare part dispatch by a service provider to the customer is ideally complimented by a faulty part being returned back by the customer. Hence, every part that the service provider sends to a customer is followed by the customer replacing the non-functional part and sending it back. Unfortunately, the service providers lose over millions of dollars globally to non-returned parts and system exchanges. Neither are the companies tracking whether the parts or systems are being returned or not, nor are there processes in place to predict if a particular dispatch is fraudulent. A deep understanding of the dispatch process, with inputs from various stakeholders like technical support, logistics provider and customer is required. The objective of the paper is to analyze dispatch frauds and develop a methodology that helps in avoiding and catching a fraudulent dispatch before it takes place, and hence, save millions of dollars in parts intake and sent. The steps followed to build this methodology are: 1. Recognizing and defining the metrics that help in identifying a machine on which a fraudulent dispatch has taken place 2. Carrying out primary analysis to gain a deeper understanding of the data and the fraud process as a whole 3. Performing cluster analysis to group and characterize the features of such a machine and hence draw inference about possible machines on which fraud dispatch would have happened or can happen The propensity of a machine to commit fraud is used to flag the machine and to serve as an alert when the service provider is contacted for another dispatch. Subsequently, very high risk machines can be blocked for no future dispatches.

## ■ WB-21

Wednesday, 11:00-12:30 - Seminarraum 405/406

### Stochastic and Exact Vehicle Routing

Stream: Logistics, Routing and Location Planning

Chair: *Philipp E.H. Salzmann*

#### 1 - Routing under uncertainty: a new approach to the stochastic VRP with dependent demands

*Alexandre Florio, Stefan Minner, Richard Hartl*

We present advances on the research on vehicle routing with stochastic demands under the a priori routing approach. The variant of the problem we study admits positively correlated (and thus dependent) demands, a behavior likely to be found in some practical scenarios, but rarely considered in the scientific literature. First we propose a demand model where all the demands are simultaneously affected by an external factor. Given the sequential nature of routing problems, we can update the knowledge over this factor each time a customer is visited and its true demand observed. This is accomplished by applying Bayesian learning methods. Based on the demand model we propose a stochastic dynamic programming algorithm to compute an optimal restocking policy. Such technique is common in a priori routing problems. In our case we augment the state set to incorporate the information about the external factor. We also generalize the traditional approach by considering unbounded demands. We formalize the finite-horizon Markov decision process behind the restocking decisions and the dynamic programming algorithm, and transform this model into an equivalent linear program. We add routing constraints to this linear program, and formulate the problem of finding the optimal a priori route considering the optimal restocking policy. Finally, we present some results and discuss the validity of our approach to obtain the best possible combination of one a priori route and one restocking policy.

#### 2 - A stochastic vehicle routing problem with ordered customers and stochastic preferences and demands

*Epaminondas Kyriakidis, Theodosios Dimitrakos, Constantinos Karamatsoukis*

We develop and analyze a mathematical model for a specific vehicle routing problem that has many realistic applications. Specifically, we assume that a vehicle starts its route from a depot loaded with items of two similar but not identical products, which we name product 1 and product 2. The vehicle must deliver the products to  $n$  customers according to a predefined sequence. This means that first customer 1 must be serviced, then customer 2 must be serviced, then customer 3 must be serviced and so on. The vehicle has finite capacity and after servicing all customers it returns to the depot. It is assumed that each customer prefers either product 1 or product 2 with known probabilities. The actual preference of each customer becomes known when the vehicle visits the customer. It is also assumed that the number of items that each customer demands is a discrete random variable with known distribution. The actual demand is revealed upon the vehicle's arrival at customer's site. The demand of each customer cannot exceed the vehicle capacity and the vehicle is allowed during its route to return to the depot to restock with items of both products. The travel costs between consecutive customers and the travel costs between the customers and the depot are known. If there is shortage for the desired product it is permitted to deliver the other product at a reduced price. The objective is to find the optimal routing strategy, i.e. the routing strategy that minimizes the total expected cost among all possible strategies. It is possible to find the optimal routing strategy using a suitable stochastic dynamic programming algorithm. It is also possible to prove that the optimal routing strategy has a specific threshold-type structure.

#### 3 - Exact Approaches for the Multi Depot Travelling Salesman Problem with Pickup and Delivery

*Philipp E.H. Salzmann, Margaretha Gansterer, Richard Hartl*

The Multi Depot Travelling Salesman Problem (MDTSP) is a special case of the Pickup and Delivery Problem (PDP) and the Collaborative Carrier Routing Problem (CCRP). For the CCRP, the solution of the MDTSP is the optimal solution assuming full collaboration. We aim at the generation of optimal solutions for the MDTSP, since they are valuable benchmarks for decentralized collaborative scenarios. To the best of our knowledge, there are no exact approaches applicable to the MDTSP available in the literature. Exact approaches proposed for PDPs commonly take a lot of advantage from time window and capacity constraints, which are not part of the MDTSP. We

analyse the applicability of (i) Branch and Cut, (ii) Benders Decomposition and (iii) Column Generation for the proposed problem. We then solve MDTSP instances by Benders Decomposition based approach as well as a Branch and Cut approach based on valid (in-)equalities. The strengths and weaknesses of these approaches depending on the problem formulation are discussed.

## Wednesday, 13:30-15:00

### ■ WC-02

Wednesday, 13:30-15:00 - Hörsaal 1

#### Recent Advances in Mixed-Integer Linear and Non-linear Programming (i)

Stream: Discrete and Integer Optimization

Chair: *Dennis Michaels*

##### 1 - Maximum semidefinite extension complexity for families of polytopes

*Gennadiy Averkov, Volker Kaibel, Stefan Weltge*

We present a result that provides bounds on the maximum extension complexity (both linear and semidefinite one) for general families of polytopes. Various bounds on the maximum extension complexity of 0/1-polytopes and polygons can be derived by a straightforward application of this result.

##### 2 - Valid linear inequalities and nonlinear cutting planes for MINLP

*Sönke Behrends, Anita Schöbel*

We consider the problem of minimizing a polynomial objective subject to polynomial and integrality constraints. Instead of solving the problem directly we investigate promising geometric properties of closely related sets: The set of all feasible solutions, its continuous relaxation and the set of all optimal solutions. Specifically, we search for half-spaces, seminorm balls and ellipsoids that encompass the aforementioned sets. As these objects correspond to linear and nonlinear valid inequalities, this can be reformulated by means of auxiliary programs. We give tractable relaxations for these auxiliary programs in terms of a hierarchy of sos programs. Also, we give necessary and sufficient conditions for the convergence of the optimal values of the hierarchies towards the optimal values of the auxiliary programs. In the case of nonlinear valid inequalities we may use arguments from (elementary) number theory that allow to tighten the inequalities further. This potentially cuts off points from the continuous relaxation, thus yielding a nonlinear cutting plane. Computational experiments show that this concept improves on earlier ideas and that the integrality arguments work in practice.

##### 3 - Solving Mixed-Integer Nonlinear Programs with hierarchical Mixed-Integer Linear Programming relaxations

*Lars Schewe, Robert Burlacu, Alexander Martin*

We show how to use a hierarchy of MILP relaxations to solve MINLP; for this we solve coarse MILP relaxations of the MINLP and refine these adaptively. For the MILP on each level of the hierarchy we can give tight bounds on the relaxation error we are making. The main problem with approaches of this type was the lack of theoretical results for nonlinearities of higher dimensions. We extend prior work to give convergence results for different variants of the method and give a priori bounds on the required size of the MILP relaxations. To show the applicability of our method we present computational results on MINLP from gas network optimization.

### ■ WC-03

Wednesday, 13:30-15:00 - Hörsaal 2

#### Applied Mixed Integer Programming (i)

Stream: Discrete and Integer Optimization

Chair: *Matthias Walter*

Chair: *Anja Fischer*

##### 1 - Solving an On-line Capacitated Vehicle Routing Problem with Time Windows

*Christian Truden, Philipp Hungerländer, Andrea Rendl, Kerstin Maier, Jörg Pöcher*

The capacitated vehicle routing problem with time windows (cVRPTW) is concerned with finding minimal tours for vehicles to deliver goods to customers within a specific time window, respecting the maximal capacity of each vehicle. In this work, we consider an on-line variant of the cVRPTW that arises in the online shopping service of an international supermarket chain: customers choose a delivery time window for their order online, and the fleet's tours are updated accordingly in real time. This means that the vehicles' tours are incrementally filled with orders.

This leads to two challenges. First, the new orders need to be inserted at a suitable place in one of the existing tours. Second, the new orders have to be inserted in real time due to high customer demand. This is why we apply a computationally cheap, two-step approach consisting of an insertion step and an optimization step.

For the insertion step we first try a simple insertion heuristic. If unsuccessful, our heuristic is preceded by a mixed integer linear program (MILP) that is solved as a feasibility problem. The MILP models a single time window across all tours. Thus it exploits the special structure of the time windows in our application: each time window contains many orders, and all have the same length.

For the optimization step, we iteratively apply two exact approaches to different tours and time windows: the time window based MILP from above augmented by an objective function in order to minimize the sum of the travel time of all tours. And a MILP for the traveling salesman problem with time windows that optimizes single tours.

In an experimental evaluation, we demonstrate the efficiency of our approaches on a variety of benchmark sets.

##### 2 - Solving the Timetabling Problem of University College London

*Paul Alexandru Bucur, Philipp Hungerländer, Markus Aschinger, Kerstin Maier, Sam Applebee, Harry Edmonds*

Course timetabling deals with scheduling lectures of a set of university courses into a given number of rooms and time periods, taking into account various hard and soft constraints. Since timetabling problems come in various forms, it is impossible to write a formulation that suits all cases, as every institution has its own features and conditions. However, the goal of the International Timetabling Competitions ITC2002 and ITC2007 was to establish models for comparison that cover the most frequently found use cases. Our model, motivated by a project with University College London (UCL), is building on the standard model from track 3 of ITC2007. This has the advantage that we have lots of information on potential approaches and many benchmarking instances for checking the performance of our implementations against current state-of-the-art methods. Compared to the standard model from the literature, we cover several new constraints and extra features. For example, we distinguish between under- and postgraduate students and prioritize usage of the own department rooms. Furthermore, we also introduce new metrics such as Timetable Regularity, which deals with maximizing the consistency of time and room for a course throughout the term, assuming that each week of the term has slightly different courses and rooms. We consider three solution approaches: a Mixed Integer Linear Programming model, a Boolean Satisfiability solver, and a genetic algorithm hybridized with a Tabu Search heuristic. In our computational experiments we first benchmark our solvers against the traditional literature instances. Then we suggest benchmarking instances for the expanded problem. Finally we compare our solvers on this new set of benchmarks with respect to solving time and solution quality.

##### 3 - Approaches for Virtual Network Embeddings Problems with Time Windows

*Frank Fischer, Andreas Bley*

The Virtual Network Embedding Problem (VNEP) aims at embedding virtual network services in physical substrate networks. A service consists of virtual computing nodes connected by virtual links. The virtual nodes are embedded in physical nodes, virtual links are embedded to paths on the substrate network. Each service has certain demands on the available physical resources as computing time or transmission bandwidth, and multiple services may be embedded onto the same physical infrastructure as long as the capacities are not exceeded.

In the classical VNEP typically all services are embedded at the same time and the goal is to reject as less services as possible. In practice, however, services are only embedded for a certain amount of time. We consider the VNEP with time windows, where each service has additional release and due times and has to be embedded for a certain amount of time. Thus, the aim is to find feasible embeddings and a feasible schedule of the services at the same time.



We present and compare different solution approaches based on time discretised models. The most successful approach is based on a Bender's decomposition, where the master problem determines a feasible schedule and the subproblems ensure the existence of feasible simultaneous embeddings of services scheduled at the same time. With our approach we have been able to solve medium sized test instances from the literature to optimality for the first time within very short running times.

## ■ WC-04

Wednesday, 13:30-15:00 - Hörsaal 3

### Electric Mobility: Battery Technologies

Stream: Energy and Environment

Chair: *Grit Walther*

#### 1 - Stochastic Valuation of Battery Storage Systems in Second Life Applications

*Andreas Dietrich, Benjamin Böcker, Christoph Weber*

Battery storage systems are seen as a promising, but costly technology for balancing electricity demand and supply in future energy systems with high shares of fluctuating renewables. Likewise electric cars are entering automotive markets in increasing numbers. Typically, batteries in automobile applications are replaced if their capacity has reduced to 70 - 80 % of nominal capacity. The remaining capacity could be used for other purposes, hence extending the utilization period and creating additional value. However, for investors it is hard to determine the economic value associated with the battery's second life since future revenues are highly uncertain.

This presentation focuses on stochastic valuation of battery storage systems in second life applications. The developed model is based on the Least Square Monte Carlo method, considering uncertainty in future cash flows. It allows for an economic assessment and comparison of different application cases. Deterioration of the battery over time is taken into account by modeling calendrical as well as cyclical aging effects. Compared to conventional approaches based on linear programming, the implementation of nonlinear technical relations is an additional advantage of the model. The results are shown for a selected storage system configuration in a typical application.

#### 2 - Location Planning of Charging Stations for Electric City Buses Considering Battery Aging Effects

*Brita Rohrbeck, Kilian Berthold, Felix Hettich*

Fuel prices on the rise and ambitious goals in environment protection make it increasingly necessary to change for modern and more sustainable technologies. This trend also affects the public transportation sector. Electric city buses with stationary charging technology fit this development perfectly since they unburden cities from greenhouse gases and noise emissions. However, their technology and charging infrastructure is still costly, and a cost-optimal solution strongly depends on the batteries' capacities as well as on the number and locations of charging stations. The usable capacity of a battery is again greatly influenced by aging effects due to time and usage.

In our talk we discuss the parameters influencing the battery performance and deduce a capacity decrease function to incorporate the impact of battery aging. We revise shortly a basic mixed integer model that gives an optimal solution concerning the investment costs for a bus route with several busses and one time period. This model is then extended by multiple periods and battery technologies, and enhanced by a battery aging function.

We give an overview of our results obtained from real world data of the bus network of Mannheim. Technology as well as costs for batteries and charging infrastructure underlie the technical progress and are supposed to improve significantly within the next years and decades. We therefore considered different scenarios for prices, capacities and battery aging factors.

#### 3 - Integrated Planning of Charging Infrastructure for Battery Electric Vehicles considering Interdependencies with the Electrical Grid

*Barbara Scheiper, Maximilian Schiffer, Grit Walther*

Battery electric vehicles as well as renewable energies contribute to sustainable development as they lead to clean and sustainable road transportation and energy supply. However, the introduction of both technologies results in new challenges within the energy and the transportation sector, and interdependencies between both sectors have to be considered. Thus, an integrated modeling approach regarding both sectors simultaneously is necessary to take advantage of possible synergies. So far, location models for charging stations and charging models for battery electric vehicles of the transportation sector do not sufficiently consider interdependencies with capacity planning and load management models of the energy sector. Against this background, we derive an integrated planning approach for charging infrastructure of battery electric vehicles considering interdependencies with the electrical grid. Our modelling approach, the Flow Refueling Location Problem with Load Flow Control, combines a charging station location model and a power flow model with integrated energy storages. We aim at determining a network configuration that satisfies the charging demand of battery electric vehicles, thereby simultaneously aiming at maximizing the usage of renewable energies in charging processes as well as at minimizing the additional load flow within the electrical grid. To highlight the impact of our modelling approach, we present results for novel benchmark instances focusing on the parameter variation of charging stations and different generation profiles of renewable energies.

## ■ WC-05

Wednesday, 13:30-15:00 - Hörsaal 4

### Behavioral Taxation (i)

Stream: Game Theory and Experimental Economics

Chair: *Martin Fochmann*

#### 1 - Tax Incidence in the Presence of Tax Evasion

*Philipp Dörrenberg, Denvil Duncan*

This paper studies the economic incidence of sales taxes in the presence of tax evasion opportunities. We design a laboratory experiment in which buyers and sellers trade a fictitious good in double auction markets. A per-unit tax is imposed on sellers, and sellers in the treatment group are provided the opportunity to evade the tax whereas sellers in the control group are not. We find that the market equilibrium price in the treatment group is lower than in the control group. This difference is economically and statistically significant, and implies that sellers with access to evasion shift a smaller share of the statutory tax burden onto buyers relative to sellers without tax evasion opportunities. Interestingly, we find that sellers with evasion opportunities shift the full amount of their effective tax rate onto buyers. Additional experimental treatments show that the full shifting of the effective tax burden is due to the evasion opportunity itself rather than the evasion-induced lower effective tax rate.

#### 2 - Does Legality Matter? The Case of Tax Avoidance and Evasion

*Jochen Hundsdoerfer, Kay Blaufus, Martin Jacob, Matthias Sünwoldt*

Previous research argues that the law expresses social values and could, therefore, influence individual behavior independently of enforcement and penalization. Using three laboratory experiments on tax avoidance and evasion, we study how legality affects individuals' decisions. We find that, without any risk of negative financial consequences, the qualification of tax minimization as illegal versus legal reduces tax minimization considerably. Legislators can thus, in principle, affect subjects' decisions by defining the line between legality and illegality. However, once we introduce potential negative financial consequences, we observe no difference between legal and illegal tax minimization behavior. Only if we use moral priming to increase subjects' moral cost do we again find a legality effect on tax minimization. Overall, this demonstrates the limitations of the expressive function of the law. Legality might be an important determinant of behavior only if we consider activities with little or no risk of negative financial consequences or if subjects are morally primed.

#### 3 - Mental Accounting in Tax Evasion Decisions - An Experiment on Underreporting and Overdeducting

*Martin Fochmann, Nadja Wolf*

Although tax evasion costs governments worldwide trillions of US dollars, revenue bodies are increasingly confronted with reduced audit capacities. The decisions on whom to audit and what to audit therefore become essential to ensure tax evasion is combatted effectively. Using different controlled experiments, we analyze whether taxpayers are more willing to evade taxes by underreporting income (i.e., declaring less than their actual income) than by overdeducting expenses (i.e., declaring more than their actual expenses) if the benefits and costs of evasion are kept constant. We robustly observe an asymmetric tax evasion behavior and find that tax authorities are advised to pay more attention to income reporting than to expense deduction. We show that this result can be explained by mental accounting and an asymmetric evaluation of tax payments and tax refunds in accordance with prospect theory. In an experimental environment in which we expect that mental accounting has no influence on behavior, however, the effect vanishes. This provides strong evidence that mental accounting plays an important role in tax evasion decisions.

## ■ WC-06

Wednesday, 13:30-15:00 - Hörsaal 5

### Business Track 2

Stream: Business Track

Chair: *Sven F. Crone*

#### 1 - Price Optimization: From prediction to decision with Gurobi

*Hannes Sieling*

In prescriptive analytics, optimization is a key part to turn predictions into decisions. At Blue Yonder, we are using Gurobi to deliver a large number of daily pricing decisions to our customers based on our price elasticity and demand models. In this talk, we will discuss the variety of high dimensional optimization problems that emerge in price optimization and give examples on how they can be solved using Gurobi. Furthermore we will address the question of balancing precision against computation time. This is a significant part of the optimization problem for us, as our problems are large and pricing decisions need to be done almost in real time.

#### 2 - Extension of Bouygues Telecom's ADSL network

*Julien Darlay, Frédéric Gardi*

Bouygues Telecom is a leading Internet service provider in France. His broadband clients are connected by optical fiber or via an ADSL service by the telephone line. This line has one end at the subscriber and one end in a subscribers connecting nodes (NRAs). The customer is then connected either to Bouygues Telecom's equipment or a third party's equipment. In the first case, Bouygues Telecom must invest to install its equipment in the NRA and connect it to the core network, while in the second case he has to pay lease to the third party. Bouygues Telecom wants to expand his network by choosing NRAs to unbundle, in order to maximize his income under different constraints and economic assumptions.

In this presentation, we will study the problem modeled as prize collecting Steiner forest problem with additional constraints. These constraints may affect the local structure of the solution, for example by limiting the maximum degree of some nodes. They can also affect the global structure of the solution, for example by eliminating paths with too much clients to limit the impact of an incident. This resulting problem is NP-hard, while instances to solve in practice have a large scale: 15,000 nodes, 180,000 edges. Then, we present a heuristic solution approach based on LocalSolver.

The software was used by Bouygues Telecom to plan and optimize unbundling campaigns. Since our optimization software was delivered in July 2014, Bouygues Telecom has unbundled 500 new NRAs in addition to the 700 ones they already operated. This unbundling strategy allows Bouygues Telecom to offer low-cost ADSL to a much larger customer base, contributing to gain 500,000 new clients over the last year and then to reach a total number of 2.5 million ADSL clients.

#### 3 - Airport Resource Management using the 'BEONTRA Scenario Planning Suite'

*Daniel Binkele-Raible*

Due to ongoing growth of traffic airports are constantly struggling to provide a sufficient service level for passengers. This primarily boils down to having an efficient strategy of sharing the given resources at an airport. Among these resources we find 'gates', 'stands', 'check-in desks', 'baggage belts', 'security lanes', 'busses', 'towing trucks' and 'runways'. In this talk we will give a brief overview of how BEONTRA tackles these different resource-allocation-problems. We focus on two of those problems, the allocation of airplanes to gates and stands and the allocation of airlines to check-in desks. For both problems a short outline of a 'Column Generation Approach' will be given.

#### 4 - A Collaborative Filtering Approach to Fit Prediction

*Josef Feigl*

OTTO.de is one of the largest online retailer for fashion in Germany. The fashion segment suffers from high return rates, often caused by customers choosing an inappropriate size or by orders of the same product in different sizes. The decision process to find the correct size is often difficult and fuzzy. Typical instruments to help customers, like conversion tables, are often complicated or simply not very helpful. The Otto Group's Business Intelligence unit developed a service based on collaborative filtering techniques to help customers in this difficult decision process to find their correct size. This talk will give a walk-through on the modelling, evaluation and deployment process of this service.

## ■ WC-07

Wednesday, 13:30-15:00 - Hörsaal 6

### Coordination Mechanisms in Logistics (i)

Stream: Game Theory and Experimental Economics

Chair: *Tobias Buer*

#### 1 - Impact of Non-truthful Bidding on Transport Coalition Profits

*Jonathan Jacob, Tobias Buer*

A relevant but rarely studied issue of freight carrier coalitions is opportunistic behavior by carriers. We consider a scenario where a set of pickup and delivery requests is being partitioned among a set of carriers by means of a bidding-based coordination mechanism. Approaches in the literature usually assume truthful bidding, although this is not enforced by the used coordination protocol. In this contribution, we consider a genetic algorithm-based coordination mechanism which proposes request allocations to the carriers. The carriers iteratively bid on these allocations. Each carrier's bid price may be positive or negative. The goal of the mechanism is to maximize the surplus, i.e., the sum of the bid prices of the coalition. If the surplus of the final allocation is positive, each carrier fulfills its bid and obtains an even share of the surplus. Two questions are studied: First, can bidders improve their expected outcome by bidding non-truthfully, i.e., bidding more or less than their actual marginal profit? Second, how is the surplus of the coalition affected by this bidding behavior? For this purpose, we perform computational experiments and evaluate the results obtained over a set of test instances where a parameter for over- or under-bidding is varied.

#### 2 - An agent-driven negotiation protocol with Aumann/Maschler nucleolus side payments for a distributed lot-sizing problem

*Gabriel Franz Guckenbiehl, Tobias Buer*

Production decisions are distributed throughout a supply chain. In order to minimize the total cost of a supply chain, multiple agents have to coordinate their decisions. In this setting, our focus is on a distributed capacitated multi-level lot-sizing problem which has to be jointly solved by multiple agents. To solve this problem, we developed a negotiation scheme. Agents negotiate a contract which consists of delivery dates for each item. Rotationally, agents propose contract modifications. Based upon a given contract proposal, an agent identifies an item with a high potential for cost savings within her schedule. She proposes a corresponding modification of the contract; the other agents re-evaluate the modified contract and indicate their preferences for it via voting. Concurrently, each agent reveals changes in her local costs. Based on these, payments are collected which can be used to compensate some agents for deviating from their local optima. In order to calculate the actual side payments, a technique from cooperative

game proposed by Aumann and Maschler in 1985 is used. In contrast to other mechanisms, there is no requirement to publish production setup decisions or production cost per item, and the side payments are based upon game-theoretic procedures. The performance of the mechanism will be evaluated by means of computational study.

### 3 - Credible information sharing in supply chains - A behavioral assessment of review strategies

*Guido Voigt, Stephan Schosser, Bodo Vogt*

In laboratory experiments, we compare the ability of trigger strategies with that of (relatively complex) review strategies to coordinate capacity decisions in supply chains when demand forecasts are based on private information. While trigger strategies punish apparently uncooperative behavior (misstated demand forecasts) immediately, review strategies only punish when apparently misstated information culminates over several periods. We contribute to the existing literature on capacity coordination in supply chains by showing that repeated game strategies lead to a significant degree of forecast misrepresentation, although they theoretically support the truth-telling equilibrium. However, forecast misrepresentation is more pronounced in review strategies. This behavioral effect is diametrically opposed to the theoretically predicted benefit of review strategies.

## ■ WC-08

Wednesday, 13:30-15:00 - Seminarraum 101/103

### Cross Docking and Stochastic Approaches

Stream: Logistics, Routing and Location Planning

Chair: *Lars Eufinger*

#### 1 - Combining mathematical optimization with discrete-event simulation to improve cross docking operations

*Daniel Diekmann, Uwe Clausen, Lars Eufinger, Gülgün Alan, Anne-Laure Ladier*

Cross docking is a logistic technique which seeks to reduce the inventory holding and transportation costs as well as delivery time. In order to successfully operate a cross docking terminal, different resources - such as vehicles and workers - need to be scheduled, allocated and synchronized in the best possible way. Several models have been developed which mainly use either mathematical optimization or (discrete-event) simulation. Simulation-based approaches allow a very realistic modelling of cross docking facilities. Complex processes can be implemented in detail including stochastic behaviour. However, finding the best system configuration is very difficult and time-consuming since there are usually many strategies and/or configurations that need to be evaluated. In contrast, approaches that are based on mathematical optimization have the ability to make complex decisions and find (near) optimal solutions. But to solve real world logistic problems they are usually implemented on a lower level of details and without stochastic behaviour. Joint optimization and simulation approaches have recently been proven promising and are therefore getting increasingly relevant to handle complex industrial planning and scheduling problems. This work discusses different methodological approaches to combine mathematical optimization and simulation in order to make use of their complementary advantages. Potential options for linking both modelling paradigms are presented. In addition to that, modelling issues and technical aspects are shown by different application examples.

#### 2 - Two-Stage Stochastic Truck Assignment and Scheduling in Crossdocking Terminals using Hybrid Evolutionary Optimization

*Lars Eufinger, Uwe Clausen*

Crossdocking is a warehouse management concept in which goods delivered to a warehouse by inbound trucks are immediately sorted out, reorganized based on customer demands and loaded into outbound trucks for delivery to customers, without requiring excessive inventory at the crossdocking terminal. Compared to traditional warehousing, the storage as well as the length of the stay of a product in the warehouse is limited, which requires an appropriate coordination of inbound and outbound trucks. Many uncertain factors influence the planning. Especially fluctuations in the arrival times of vehicles have great impact

on the planning process. To handle the occurring uncertainties we use a two-stage stochastic mixed-integer program, which is handled by a stage-decomposition based hybrid algorithm. An evolutionary algorithm determines the first-stage decisions and mathematical programming determines the second-stage decisions. In the two-stage model for the truck assignment and scheduling problem, the assignments of the trucks to the gates are used as the first stage decision variables. All remaining variables, e.g. the assignment times of the trucks, are the second stage decision variables. Which means, in the first stage, a gate assignment is determined. The quality of the assignment is evaluated in the second stage, where the assignment times and the transports of the goods inside the facility are determined for the given scenarios.

#### 3 - A parallel matheuristic for strategic planning of a closed-loop supply chain with a time stochastic dominance risk averse functional measure

*Susana Baptista, Ana Barbosa-Povoa, Laureano Fernando Escudero, Maria Isabel Gomes, Celeste Pizarro Romero*

Closed loop supply chains are object of a growing interest both from academia as well as industry. Not only do they comply with the expectations of a more environment sustainability management, but also they allow management decisions to be less exposed to raw materials variability, either in prices or availability. In this work, we focus on forward and reverse supply chains operated by the same equipment manufacturer, where recovered products from customers are end-of life products and where products follow, in the reverse chain, different paths according to their quality. In modeling the design and operational decisions of the supply chain, most of the problem parameters, either in operational decisions as in financial aspects, are not known with certainty, but some information is available in the form of a finite set of scenarios. In particular, raw material cost, transportation cost, product demand and price, returned product volumes and returned product evaluations were considered to be uncertain, as well as available budget for investment, amortization costs and entities residual values. From a mathematical perspective, we propose a two-stage stochastic mixed 0-1 programming model, whose risk management is performed by using a risk averse strategy based on a time stochastic dominance functional. This functional ensures for a modeler-driven set of profit thresholds, the bounding of the expected fraction of scenarios with profit shortfall and the bounding of the expected profit shortfall. In order to effectively solve this large scale mixed integer problem, we propose as a solution procedure, a parallel extension of the Fix-and-Relax matheuristic algorithm. Some computational experience conducted on randomly generated networks shows the quality of the approach

## ■ WC-09

Wednesday, 13:30-15:00 - Seminarraum 105

### Finance II

Stream: Finance

Chair: *Marco Wilkens*

#### 1 - Applying a Novel Investment Evaluation Method with Focus on Risk - A Wind Energy Case Study

*Jan-Hendrik Piel, Felix Humpert, Michael H. Breitter*

Renewable energy investments are typically evaluated using traditional discounted cash flow methods, such as the net present value (NPV) or the internal rate of return (IRR). These methods utilize the discount rate as an aggregate proxy for risk and the time value of money, which leads to an inadequate modelling of risk. An alternative to these methods represents the decoupled net present value (DNPV): a novel and practical concept for decoupling the time value of money from the risk associated with investments. Instead of accounting for risk in the discount rate, the DNPV utilizes so-called synthetic risk premiums. These allow for individual and disaggregate pricing of risk and enhance the quality of investment decisions due to a more detailed and comprehensive representation of the underlying risk structure. After reviewing the main theory of the DNPV, we apply the method to a wind energy investment case in order to demonstrate its applicability and prospects. For this purpose, we implement a cash-flow model in the programming environment MATLAB. To illustrate the calculation of the synthetic risk premiums, selected risk factors are modelled with probability distributions via Monte Carlo simulation. Our results show that the DNPV's seamless integration of risk assessment with investment evaluation is a very promising combination and warrants further research.

**2 - Are Momentum Strategies Feasible in Intraday-Trading? Empirical Results from the German Stock Market**

*Matthias Horn, Tim Herberger, Andreas Oehler*

Momentum trading strategies have been proved to be profitable in different asset classes and on various national capital markets in the past. However, there are some indications for eroding momentum profits. Based on the theory of gradual information distribution on capital markets and the technological progress of the last years, we suppose that the momentum effect transformed from a monthly basis to shorter time horizons. With regard to stocks that were listed in the German blue chip index DAX 30 between November 2013 and December 2014, this study is the first to examine, whether such strategies generate market adjusted excess returns on an intraday-trading basis. We analyze 16 momentum strategies, inspired by Jegadeesh/Titman (1993) and Jegadeesh/Titman (2001) original momentum strategy design (4x4), with ranking and holding periods of 15, 30, 45 or 60 minutes. For each stock, we analyze 27,219 price observations on a five minutes frequency. From the empirical results we conclude that momentum strategies do not provide positive excess returns. However, we find indications for price reversals in intraday stock market returns for past loser stocks. Our results are robust on portfolio size (winner- as well as loser-portfolio), on the duration of the lag between the ends of the formation ranking periods and the beginnings of the holding periods as well as on the influence of trading-time and on the market price trend.

**3 - Quantification and Management of Carbon Risks of Stocks and Stock Portfolios**

*Marco Wilkens, Martin Nerlinger*

Today there is no doubt about climate change mainly driven by carbon emissions and equivalents (IPCC Fifth Assessment Report, 2013). This leads to many new legislations and regulations worldwide aiming the 2°C target, agreed between 195 nations at the 21st Conference of the Parties in Paris (2015). The corresponding and already started transformation process towards a "Green Economy" affects nearly all parts of the society and the whole economic system including the financial systems. Our paper helps to identify and manage the risk for stocks and stock portfolios, related to this transformation process of the economy, the so called "carbon risk". The relevance of carbon risks can already be seen in "stranded assets" and the "carbon bubble" (Carbon Tracker Initiative, 2011). Since carbon risk is a kind of systematic risk, it is highly relevant not only for single companies or investors, but for the whole financial system (ESRB, 2016). Based on the Fama and French's three-factor model (1993) and Carhart's four-factor model (1997), we introduce, estimate and verify a new factor model including a set of carbon risk factors, derived from carbon dioxide emissions and diverse other fundamental data of more than 2,000 companies worldwide. Applying this factor model we are able to quantify the carbon risk of potentially all stocks and stock portfolios worldwide. Using an out-of sample hedging approach we further show that our model enables to hedge large parts of the carbon risk of stock portfolios. Over all our paper support investors and funds as well as regulators and politics to comprehend and manage the risks for financial assets due to the worldwide started transformation process towards a "Green Economy" originating by climate change.

**WC-10**

*Wednesday, 13:30-15:00 - Seminarraum 108*

**Robust algorithms**

Stream: Optimization under Uncertainty

Chair: *Marc Goerigk*

**1 - MIP-based approaches for robust storage loading problems with stacking constraints**

*Thanh Le Xuan, Sigrid Knust*

We consider storage loading problems under uncertainty where the storage area is organized in fixed stacks with a limited height. Such problems appear in several practical applications, e.g., when loading container terminals, container ships or warehouses. Incoming items arriving at a partly filled storage area have to be assigned to stacks regarding that not every item may be stacked on top of every other item and taking into account that some items with uncertain data will arrive

later. Following the robust optimization paradigm, we propose different MIP formulations for the strictly and adjustable robust counterparts of the uncertain problem. Furthermore, we show that in the case of interval uncertainties the computational effort to find adjustable robust solutions can be reduced. Computational results are presented for randomly generated instances with up to 480 items. The results show that instances of this size can be solved in reasonable time and that including robustness improves solutions where uncertainty is not taken into account.

**2 - A Method for Solving Multiple Integer Linear Programming Stochastic Problem**

*Meberek Fatma, Chaabane Djamel*

In this paper we study the problem of optimizing an aggregate function over an integer efficient solution set of a Multiple Objective Integer Linear Programming Stochastic problem (MOILPS). Once the problem is converted into a deterministic one by adapting the two-levels recourse approach, a new pivoting technique is applied to generate all efficient solutions. The combination of both approaches, L-Shaped and the aggregation of objective method, enables us to produce the whole set of all non-dominated stochastic integer solutions.

**3 - Solving Combinatorial Min-Max Regret Problems with Non-Interval Uncertainty Sets**

*Marc Goerigk, André Chassein*

In min-max regret optimisation, the most widely used uncertainty sets are intervals (hyperboxes). They have the advantage that finding a worst-case scenario for a given solution is easy, and even allow compact reformulations as a mixed-integer programme if the original problem can be formulated as a linear programme.

In this talk we consider different uncertainty sets, which are relevant in practice, but so far have not been considered in min-max regret. We consider the problem complexity, present an approximation algorithm, and discuss exact solution approaches. Different approaches are compared in numerical experiments.

**WC-11**

*Wednesday, 13:30-15:00 - Seminarraum 110*

**Lot Sizing**

Stream: Production and Operations Management

Chair: *Florian Isenber*

**1 - Integrated safety stock placement and lot-sizing in capacitated production networks**

*Tarik Aouam, Kunal Kumar*

In capacitated production networks, strategic safety stock placement and tactical lot-sizing are typically treated as independent decisions when, in reality, they are linked through production cycle times (PCTs). On the one hand, PCT of a capacitated resource depends on lot-sizing and its congestion effects, on the other hand, the size and placement of safety stocks depend on the demand over a replenishment period that includes PCT. Therefore, treating safety stock placement and lot-sizing decisions as independent would erode the performance of production networks. In this study, we model and solve the integrated strategic safety stock placement and lot-sizing problem in the context of a capacitated production network facing uncertain demand of a single product. Each stage in the production network is modeled as a series of a raw-material inventory, a production workstation and a finished-goods inventory. We follow the guaranteed-service approach to model the safety stock placement problem, where stages are coordinated through quoted guaranteed service times. The finished goods inventory is assumed to operate under a periodic review base-stock policy, with a common review period between stages. The production station is modeled as a G/G/1 system with setup time and cost. An optimization problem that jointly determines the optimal lot-sizes and safety stock placement is formulated. Analysis of the problem allows us to establish bounds for lot-sizes, which are then used to develop an efficient dynamic program that solves the problem in polynomial time. Based on numerical experiments the efficiency of the algorithm and the value of integrating the two decisions are demonstrated and practical insights and recommendations are derived.

## 2 - Planned lead times, safety stocks, and lot sizing in capacitated production networks

Kunal Kumar, Tarik Aouam

The optimization of planning parameters in capacitated production networks facing supply and demand uncertainty is considered. Each stage includes a series of a raw-material inventory, an M/M/1 production workstation with batching and setup time, and a finished-goods inventory. The finished goods inventory operates under a periodic review base-stock policy, with a common review period between stages. Stages are coordinated through quoted guaranteed service times. In this setting, the size and placement of decoupling safety stocks depend a replenishment period that includes random production cycle times. Batching or lot-sizing decisions have congestion effects, due to limited capacity, which affect mean and variance of production cycle times. To control the variability inherent in production cycle times, we use a production control policy with planned lead times and flexible capacity (overtime or subcontracting). Based on a planned lead time, the control policy sets the production rate proportional to the workload, and unlimited flexible capacity processes workload exceeding workstation capacity. In this way, the promised service time is guaranteed. While, higher planned lead-times reduce variability and increase inventory in the system, production flexibility incurs high costs. The problem of jointly setting safety stocks, lot-sizing and planned lead times to minimize the total operational cost subject to service time constraints is formulated and solved. We establish bounds for lot-sizes and planned lead-times and use these bounds to develop a dynamic program that solves the problem in polynomial time. Numerical experiments demonstrate the efficiency of the proposed algorithm and a sensitivity analysis on key parameters is carried out to provide practical insights.

## 3 - Lot sizing and scheduling for manufacturing with tooling machines

Florian Isenberg, Leena Suhl

Practically all manufacturing companies today face constant change. The growing globalization and the rapid technical development offer new opportunities and risks. Additional competitors and an intensified competition increase the pressure to act. Companies using tooling machines are no exception. The machines used by such companies to process metal are highly advanced but offer little potential for improving the processing itself. A holistic view on the production system, however, provides an opportunity for cost savings and optimizations. Besides the various requirements, challenges and practical problems given by these companies, the special possibilities enabled by the tooling machines will be presented. To cope with these requirements and opportunities a two-level concept for lot sizing and scheduling is presented. The concept combines two different lot sizing and scheduling models from the literature into an integrated one. Each of the two models has a different temporal scope and an adjusted level of detail. The solution behavior and solution quality is analyzed for different test instances, and the advantages and disadvantages of such a two-level concept are pointed out.

## ■ WC-12

Wednesday, 13:30-15:00 - Seminarraum 202

### Variable Neighbourhood Search

Stream: Metaheuristics

Chair: Martin Josef Geiger

#### 1 - Minimum Labelling bi-Connectivity

José A. Moreno-Pérez, Sergio Consoli

A labelled, undirected graph is a graph whose edges have assigned labels, from a specific set. Given a labelled, undirected graph, the well-known minimum labelling spanning tree problem is aimed at finding the spanning tree of the graph with the minimum set of labels. This combinatorial problem, which is NP-hard, can be also formulated as to give the minimum number of labels that provide single connectivity among all the vertices of the graph. Here we consider instead the problem of finding the minimum set of labels that provide bi-connectivity among all the vertices of the graph. A graph is bi-connected if there are at least two disjoint paths joining every pair of vertices. We consider both bi-connectivity concepts: the edge bi-connectivity where these paths cannot have a common edge and the vertex bi-connectivity

where the paths cannot have a common vertex. We describe our preliminary investigation on the problem and provide the details on the solution approaches for the problem under current development.

#### 2 - A VNS Approach for Solving the Maximum Dispersion Problem

Mahdi Moeini, Oliver Wendt

Consider a set of objects such that each of them has its individual (non-negative) weight. The objective of the Maximum Dispersion Problem (MDP) consists in finding a partition of this set into a predefined number of groups, such that the overall dispersion of elements assigned to the same group is maximized. Furthermore, each group has a target weight and the sum of the weights of all objects, assigned to the same group, needs to meet a specific interval around the target weight. The maximum dispersion problem can be formulated as an Integer Programming (IP) problem. However, the MDP is NP-hard and, consequently, difficult to solve by exact algorithms. In this work, we present Variable Neighbourhood Search (VNS) heuristics for solving the maximum Dispersion problem. In order to evaluate the efficiency of the proposed method, we test it on randomly generated instances and compare the results with the solutions of the standard IP solver Gurobi. According to the numerical results, for solving MDP, the VNS approach is more efficient than the Gurobi.

#### 3 - Analyzing the order of neighborhood operators in an iterated Variable Neighborhood Search

Sandra Huber, Martin Josef Geiger

In an iterated Variable Neighborhood Search (VNS) decisions must e.g. be made about the number of neighborhood operators and what sequence should be applied. With the aim of determining a sequence for the Swap-Body Vehicle Routing Problem (SB-VRP), we propose an experimental setting to test and analyze the order of neighborhood operators in a VNS. The findings of the experiments show that the order matters. Without further adaption of the algorithm, and by only modifying the sequences of operators, best known solutions can be improved with a maximal improvement of 2.25% and an average improvement of 0.70%. These results are promising and recommend to spend some time on finding an encouraging sequence which enhances the solution quality. Experiments on benchmark instances are conducted and compared for the SB-VRP.

## ■ WC-13

Wednesday, 13:30-15:00 - Seminarraum 204

### Multiobjective Linear Optimization II

Stream: Control Theory and Continuous Optimization

Chair: Oliver Stein

#### 1 - Multi-criteria decision making with variable weight function

Bettina Zargini

Selecting appropriate weights of criteria is a significant part of decision making process, since the varied weight of criteria represents different result of alternatives ranking. In many multi criteria decision making methods, weights of criteria are used to represent the importance of criteria and to compare the alternatives with respect to them. In many problems, there are different weights of criteria respect to each alternative, therefore it is more efficient to consider the weight of criteria with respect to alternatives, this helps us to make better decisions. This model can be useful in several decision making methods such as: AHP, TOPSIS, ELECTRE, PROMETHEE, etc. In this paper, we suppose a variable weight function of criteria with respect to preferences of alternatives and applications in PROMETHEE method.

#### 2 - An inertial proximal point method for solving vector optimization problems

Sorin-Mihai Grad

We present an iterative proximal method of inertial type with memory effects based on recent advances in scalar convex optimization that is employed for solving a class of convex vector optimization problems without scalarizing them first, by making use of some adaptive scalarization techniques.

### 3 - Solving Disjunctive Optimization Problems by Generalized Semi-infinite Optimization Techniques

Oliver Stein, Peter Kirst

We describe a new possibility to model disjunctive optimization problems as generalized semi-infinite programs. In contrast to existing methods in disjunctive programming, our approach does not expect any special formulation of the underlying logical expression. Applying existing lower level reformulations for the corresponding semi-infinite program we derive conjunctive nonlinear problems without any logical expressions, which can be locally solved by standard nonlinear solvers. Our preliminary numerical results indicate that our reformulation procedure is reasonable.

## ■ WC-14

Wednesday, 13:30-15:00 - Seminarraum 206

### Multiobjective Location and Routing Problems

Stream: Decision Theory and Multiple Criteria Decision Making

Chair: Kathrin Klamroth

#### 1 - Modelling Outliers in Center Location Problems - A Multiobjective Perspective

Teresa Schnepfer, Kathrin Klamroth, Michael Stiglmayr

Location models typically use the distances to all customer locations for the assessment of the service provided by a new facility. Particularly when locating central facilities, i.e. when using a center objective function, the optimal new location is sensitive to outliers among the customer locations that are located far away from the majority of customers.

We model the exclusion of very distant facilities in a center location problem by using k-max functions: Not the maximal, but the k-th largest distance should be minimized, with  $k \geq 1$ . The selection of a suitable value of k asks for a multiple objective analysis of the problem. We show that the complete non-dominated set of this biobjective optimization problem (number of outliers versus original objective function value) can be determined in polynomial time. We particularly focus on weighted problems, where customer locations are weighted according to their relative importance. We discuss strategies of incorporating weights in k-max location problems.

#### 2 - Optimally solving the TSP on acyclic networks with soft due dates and multiple congestion scenarios

Stefan Bock

In this talk, an extension of the well-known Line-TSP is considered. In this extension, an optimal schedule is sought that services all customers by using an acyclic system of predetermined transportation paths. In order to deal with unreliable data, different congestion scenarios are integrated. These scenarios are determined by specific travel times. Moreover, each customer possesses a soft due date. Although a violation of due dates is possible, it is assumed that the cost effect of the resulting tardiness is significant. Therefore, the hierarchical objective function pursues the finding of a tour schedule that primarily minimizes the total tardiness over all scenarios. As a secondary objective, the makespan of the schedule is minimized. This talk analyzes the complexity status of different variants of the model. While the NP-hardness is proven for some variants, an efficient pseudo-polynomial solution approach is proposed for cases in which processing times at the delivery locations are negligible in comparison with the travel times and the numbers of scenarios and transportation paths are constant.

#### 3 - Optimal placement of weather radars network as a multi-objectives problem

Redouane Boudjemaa

In this work we propose an approach to the optimal site locations for the installation of weather radars as a solution to a multi-objective optimization problem. By considering a finite number of weather radars and a restricted geographical region, different network architectures are produced by taking into account different objectives simultaneously such as the maximization of network coverage area, minimization of network general cost, and the reduction of environmental impact. Constraints on the solutions are considered such as topography obstacles, maximum radar beam elevation and distance from wind

farms. Multiple Geographical information system data sets are used in the analysis of different sites locations and as a result a more realistic network is generated. The search space is discretized into a gridded system which allows a reduction in the number of possible combinations of radar networks and thus effectively making the optimal placement problem manageable in size and execution time. Evolutionary methods are utilized in solving the multi objective optimization problem. The obtained results are analyzed using different performance metrics. Different combinations of different types of radars spread in different topographies are also considered in this work. By producing different set of Pareto optimal solutions, the proposed approach can serve as an analysis tool for meteorologist and climatologist in the selection of future prime sites for the installation of weather radars.

## ■ WC-15

Wednesday, 13:30-15:00 - Seminarraum 305

### Scheduling Problems and Applications (i)

Stream: Project Management and Scheduling

Chair: Ethem Canakoglu

#### 1 - ILP-based Modulo Scheduling for High-level Synthesis

Julian Oppermann, Andreas Koch, Melanie Reuter-Oppermann, Oliver Sinnen

A high-level synthesis system automatically compiles a sequential C program into a hardware accelerator to be realised on a field-programmable gate array (FPGA). In this context, loop pipelining is a technique to improve the throughput of these accelerators by starting new loop iterations after a fixed amount of time, called the initiation interval (II), allowing to overlap subsequent iterations. The problem is to find the smallest II and corresponding operation schedule that fulfills all data dependencies and resource constraints, both of which are usually found by modulo scheduling.

We present Moovac, an ILP formulation for the modulo scheduling problem based on overlap variables to model exact resource constraints and compare it to the state-of-the-art Modulo SDC heuristic. We examine kernels from the CHStone and MachSuite benchmarks, scheduling them for loop pipelining using both Moovac and Modulo SDC, and compare the results. Moovac has competitive performance in its time-limited mode, and delivers better results faster than the Modulo SDC scheduler for some loops. Using the Moovac-computed optimal solutions as a reference, we can confirm that the Modulo SDC heuristic is indeed capable of finding optimal or near-optimal solutions for the majority of small- to medium-sized loops. However, for larger loops the two algorithms begin to diverge, with Moovac often being significantly faster to prove the infeasibility of a candidate II. This can be exploited by running both schedulers synergistically, leading to a quicker convergence to the final II. We will also discuss possibilities to determine the minimal II together with the optimal schedule.

#### 2 - Audit Scheduling in Banking Sector

Ethem Canakoglu, Ibrahim Muter, Onur Adanur

The scheduling of activities in an organisation has been an interesting topic in the literature. The problems include a set of tasks to be performed, resources used in performing the tasks, and some certain constraints (resource capacity, time limitations, etc.). One variation of these problems is the assignment and scheduling of the activities in an audit environment, which is called audit staff scheduling in general.

The firms in financial sector are required to carry on regular audit activities for the local branches. The audit plan is done semi-annually and the audit team visits are scheduled for the upcoming period. Usually, in this type of problem, there is a set of auditor with different capabilities, and a bunch of branches corresponding to the activities, and the time limitations as deadlines and flow times. The team assigned to the branch should have enough skill level for the branch. The objective of this problem is to assign the teams of staff to branches for a given time period in order to audit maximum number of branches. The problem size increases exponentially as the size of audit department, number of branches and length of the planning horizon increases. Therefore we propose different heuristic methods for the solution of problem and compare the results of these approaches.

## ■ WC-16

Wednesday, 13:30-15:00 - Seminarraum 308

### Appointment Scheduling

Stream: Health Care Management

Chair: *Manuel Glaser*

#### 1 - Strategies for Improving Block Appointment Schedules at Specialty Clinics

*Rajesh Piplani, Eva Fancev*

Appointment scheduling is used by specialty care clinics to manage access to the most critical resources in the clinic. Many factors affect the performance of appointment scheduling systems, including arrival and service time variability, patient no-shows, walk-ins, and emergency cases. The goal of a well-designed appointment system is to deliver timely access to clinic's services, while maximizing the utilization of clinic's critical resources. Appointment management for specialty care clinics is made more challenging due to the fact that the clinic may have to reserve capacity for urgent cases, referred by general practitioners, while ensuring high utilization of more expensive specialists' time. Most appointment systems follow a multiple block schedule where a fixed number of patients are given appointment in each block during the day, each day being divided into certain number of blocks. While this ensures that a certain number of patients are always waiting for the specialist, ensuring their high utilization, the service time variability and cancellation and walk-ins complicate the management of patients' waiting times. In this research, we investigate strategies to improve traditional block appointment schedules by segregating different categories of patients and scheduling them on different days or at different times of the day. We study the operations of a specialty eye-care clinic, collect detailed data on patients processing over a week, and analyse improvements to segregated block schedules by means of a detailed simulation model of the clinic.

#### 2 - Interday appointment scheduling and capacity allocation in primary care

*Matthias Schacht*

Patient occurrence per weekday varies significantly in primary care. This is due to the differing number of walk-in patients (walk-ins) during a week who seek for a same-day treatment. Such walk-ins join the practice of a primary care physician (PCP) especially at the beginning of the week. In addition to walk-ins there are patients who book their appointments in advance (preschedules). For preschedules who prefer a given appointment on a specific time and day, appointment slots are provided. By offering appointment slots on days with a small expected amount of walk-ins, capacity and demand for treatment can be matched leading to a more balanced utilization for the PCP and to lower waiting times for patients. First concepts of interday appointment schedules exist in literature and increase patient as well as PCP satisfaction to a limited extent. While the occurrence of preschedules can be assigned to appointment slots, walk-in patients join the clinic uncontrolled. Because of this the capacity for treatments should be matched with demand which cannot be completely scheduled. Thus, we extend current interday appointment scheduling models by integrating capacity adjustments in terms of varying clinic opening hours. We present a concept for an extended MILP whose optimal solutions on the tactical level are evaluated in an extensive simulation study on the operational level where uncertain patient occurrence, treatment times and emergencies are considered. It is shown that slightly adjusting opening hours with respect to treatment demand has an impact on patient as well as on PCP objectives, while overall capacity is kept constant.

#### 3 - Scheduling appointments based on probabilities for patient's presence

*Manuel Glaser, Jens Brunner*

Optimizing appointment schedules without considering the variability of service times lead to a valid but only in rare cases feasible solution. Treatment durations, which are shorter than expected, cause idle times of medical personal and resources. Longer than expected treatment durations shift the start time of subsequent treatments into the future and cause additional waiting times for patients. The introduced model uses the probabilities of patient's attendance to optimize a complete appointment schedule. Therefore, treatment periods are partitioned in several time slots. For each slot, the probability for patient's presence during a treatment period are calculated based on a treatment durations representing cumulative distribution functions. The optimization shifts the appointments to slots where the respective probabilities

for patient's presence is balanced concerning to the weighted idle and waiting times. We show first experimental results to demonstrate the approach.

## ■ WC-17

Wednesday, 13:30-15:00 - Seminarraum 310

### Supplier Selection and Closed-Loop Supply Chains

Stream: CANCELED

## ■ WC-18

Wednesday, 13:30-15:00 - Seminarraum 401/402

### Truck and Trailer Routing

Stream: Logistics, Routing and Location Planning

Chair: *Joachim Kneis*

#### 1 - Solving a Rich Intra-facility Steel Slab Routing Problem

*Biljana Roljic, Fabien Tricoire, Karl Doerner*

We optimize the routing of steel slabs between locations in a steel producing facility during a one hour-long operational period. Steel slabs are heterogeneous items that appear at locations at different release times. Each slab should be delivered to another location before its specified due time. They are transported by fleets that include standard vehicles as well as truck-and-trailer type vehicles. Due to incompatibilities between slabs and vehicles, not every vehicle type can transport all types of slabs. The vehicles visit several locations multiple times. Also, it is feasible to simultaneously transport multiple slabs. The input is such that not all slabs can be delivered in time, therefore two objective functions are provided that are organized in a lexicographic fashion: First, we maximize the throughput. Second, we aim to minimize travel times. We provide a mathematical formulation for our routing problem. An exact solution can only be obtained for small problem settings. In order to solve larger instances, we developed a heuristic. The results show that the solutions obtained by the heuristic are competitive to real world solutions provided by our industrial partner.

#### 2 - Branch-Price-and-Cut for the Truck and Trailer Routing Problem with Time Windows

*Ann-Kathrin Rothenbacher, Michael Drexel, Stefan Irnich*

We consider the truck-and-trailer routing problem with time windows (TTRPTW). The fleet consists of several lorries which may attach a trailer. As some customers are not accessible for a lorry with the trailer attached, the trailers can be parked at customer sites or additional transshipment locations. When a lorry returns to its trailer after a subtour, load can be transferred from the lorry to the trailer. We extend the TTRPTW planning horizon to two days and allow customers to be visited either on both days or on only one day (in which case twice the daily supply must be collected), and we consider that the time needed for a load transfer depends on the quantity of load transferred. We tackle the problem with an exact branch-and-price-and-cut algorithm and generate the columns with a label-setting algorithm. The pricing procedure uses many known acceleration techniques, e.g., a bidirectional labelling, the ng-neighbourhood, reduced networks and relaxed dominance. Moreover, we separate subset-row inequalities to strengthen the lower bounds. Computational studies show that our algorithm compares favourably with existing approaches on TTRP and TTRPTW benchmark instances known from literature.

#### 3 - A Rich Truck and Trailer Problem arising in the Steel Industry

*Joachim Kneis*

In this talk, we introduce a rich Truck and Trailer problem that arises in the steel industry. Huge steel coils are repeatedly refined until they are ready for shipment. After each refinement step, the coils are loaded onto a waiting trailer. Once the trailer is full, it is moved by a special truck to next refinement point. There, the trailer is decoupled from the truck and remains stationary until unloaded while the truck can move

on to handle some other trailer. The truck itself can never be loaded directly.

In this setting, we need to compute not only tours for the trucks, but also have to decide how trailers are moved and which trailers are used for which coils. This is important as docking space for trailers is very limited and emptied trailers thus need to be moved out of the way quickly. Moreover, providing fresh empty trailers for loading and moving loaded trailers to the next positions quickly is required to avoid production bottlenecks. Finally, efficient usage of the trucks is paramount as these have large operational costs.

Although typical real life instances are rather small compared to other routing problems, this problem is of huge importance as the involved costs can reach several hundred million dollars per year. Here, we discuss an algorithm for this problem that is implemented in a real time optimization developed by INFORM and its application at one of our customers.

## ■ WC-19

Wednesday, 13:30-15:00 - Seminarraum 403

### Delay Management and Re-Scheduling (i)

Stream: Traffic and Passenger Transportation

Chair: *Sander Van Aken*

#### 1 - Strategic Deconfliction in the European Air Traffic Flow Management Network with Column Generation

*Jan Berling, Alexander Lau, Volker Gollnick*

In the European Air Traffic Flow Management, en-route conflicts between aircraft may be avoided strategically. One option for strategic deconfliction is the allocation of alternative departure-timeslots. To find the best slots for all flights, we solve a Binary Integer Problem. In this problem, each flight is associated with linear delay costs and a departure condition. Furthermore, flights have to satisfy sector and aerodrome capacity constraints. Since conflicts involve at least two flights, there is a coupling between variables. Each potential conflict is modelled by a linear constraint, which assigns conflict costs by setting a conflict variable. However, conflict constraints of lp-relaxed variables do not trigger their conflict costs. Therefore, branch-and-bound nodes do not contain costs for relaxed conflicts, which weakens lower bounds. With a conventional solver, the deconfliction of a full-day of European air traffic takes approximately one hour. To reduce the computation times of the Network Flow Environment (NFE), we extend the pricing algorithm to perform deconfliction. This method of column generation is initiated with only a subset of possible departure-timeslots and includes more slot-options iteratively. Promising variables with reduced costs are discovered by pricing dual variables. Conflicts increase dual departure costs and thereby boost the search of alternative departure-timeslots for conflicted flights. The column generation method reduces computation times for the optimal solution of a problem with over twenty-five thousand flights by more than eighty percent.

#### 2 - Computing alternative railway timetables to deal with infrastructure maintenance works

*Sander Van Aken, Nikola Besinovic, Rob Goverde*

Increasing supply in railway networks comes at the cost of an increased need for infrastructure maintenance. Up until now, not much research has been devoted to adjusting the timetable due to long maintenance or constructions' possessions. In this article, we introduce the Train Timetable Adjustment Problem (TTAP), which for given station and open track closures, finds an alternative timetable that minimizes the deviation from the original timetable. We propose a mixed integer linear programming (MILP) model for solving TTAP, and apply retiming, reordering, short-turning and cancellation to generate alternative timetables. The model represents an extended periodic event scheduling problem (PESP) formulation and introduces new constraints for cancelling and retiming train lines, while short-turning is being applied in a preprocessing step. In order to solve larger and more complex instances, we use a row generation approach to add station capacity constraints. The model solves real-life instances for a large area of the Dutch railway network in reasonable time, and could be up-scaled to the complete Dutch network. Operators and infrastructure managers could use it to automatically generate optimal alternative timetables on the macroscopic level in case of maintenance or construction works and thus coordinating traffic for the complete network.

### 3 - A Stochastic Dynamic Programming Approach for Delay Management of a Single Train Line

*Eva König, Cornelia Schoen*

Railway delay management considers the question whether a train should wait for a delayed feeder train or not. In the literature there exist several works which analyze these so-called wait-depart decisions. The underlying models range from rules of thumb to complete network optimizations. Nearly none of them takes uncertainties regarding further delays into account. We develop a multi-stage stochastic dynamic programming (SDP) model to make wait-depart decisions in face of uncertain future delays. The SDP approach explicitly takes potential recourse actions at later stations into account in a look-ahead manner when making the decision at the current stage. The objective is to minimize via a Bellman Equation the total weighted delay of passengers at their final station. We focus on a single train line but consider effects on feeder and connecting trains. In this talk, we present the model formulation and show numerical results comparing solution quality and computational effort of our approach to simple heuristic decision rules frequently used in delay management.

## ■ WC-20

Wednesday, 13:30-15:00 - Seminarraum 404

### Smart Services and Internet of Things

Stream: Business Analytics and Forecasting

Chair: *Johannes Kunze von Bischoffshausen*

Chair: *Maria Maleshkova*

#### 1 - Realising Smart Services Through Intelligent Interfaces

*Maria Maleshkova*

Current developments in the context of the lifecycle of services are strongly influenced by new technology developments and the need for ensuring market competitiveness. Technology trends that shape the market are the proliferation of sensor technologies, and the availability of mobile devices and wearables, which enable the direct integration of their data as part of client applications. These, in combination with the overall data digitalization, lay the foundation for offering new smart services. However, despite the existing potential, currently, the actual technical implementations are usually isolated custom solutions for particular use cases, which cannot be integrated and used together, and do not support further scenarios. To this end the vision of the Web of Things (WoT) aims to leverage Web standards in order to interconnect all types of devices and real-world objects, and thus to make them a part of the World Wide Web. We take this approach one step further and introduce the concept of intelligent programmable interfaces that do not only provide remote access to resources and functionalities, but also encapsulate 'intelligence'. Smartness features can include, for instance, context-based adaptation, cognition, inference and rules that implement autonomous decision logic in order to realize services that automatically perform tasks on behalf of the users. This intelligence is implemented directly as part of the interface, instead of relying on the client or on the server to provide it. As a result, the intelligent interfaces can be used as building blocks for developing adaptive, flexible, and customizable systems. We describe in detail the key characteristics of the intelligent interfaces, and introduce a reference implementation framework.

#### 2 - Towards Smart Services based on Distributed Architectures

*Felix Leif Keppmann*

Current technological developments have a twofold impact on the development of Smart Services. On the one hand, a large and increasing amount of services, in particular Smart Services, depends on and, subsequently, is not realizable without integrated support of computer and Internet-based technologies. On the other hand, software applications and hardware systems become smaller, more modularized, and distributed (e.g., heterogeneous sensors, smart devices). While this trend lays the foundation for the development of a multitude of new Smart Services, it also introduces additional complexity - individual components have to be composed to form distributed applications. This situation is aggravated by the fact that currently, while developing distributed solutions, only interfaces and interactions, covering common use cases, are supported, while requirements of specific use cases (e.g., for enabling particular Smart Service) are difficult to realize. Our goal



is to reduce this complexity and to enable the adaptability of systems to specific use cases. We introduce an architecture for Smart Web Services, which enable the adaptation of service-based applications to the requirements of specific use cases at runtime. In addition, we present a reference implementation of this architecture, based on a combination of widely accepted Web standards and Semantic Web technologies. Our approach introduces a layer between the local functionality/data of an application and the interface, it exposes. This layer is capable to process declarative rule-based programs that can dynamically adjust the interface and interaction during deployment or runtime, based on the requirements of the herewith implemented Smart Service.

### 3 - Business analytics for managing uncertainties in industrial service contracts

*Michael Vössing, Björn Schmitz*

The industrial sector is experiencing a service transformation. Equipment providers strengthen their service business and move from product-centric spot transactions towards long-term service contracts and relational business models. While services promise continuous revenue streams, higher profitability and tighter customer relationships, many manufacturing companies still refrain from servitizing their business. Recent studies suggest that the increasing exposure to uncertainties is a major reason why providers hesitate to engage into longer-term service contracts. In such contracts, providers take over responsibilities and uncertainties from their clients. For instance, in full service maintenance contracts, providers bear the cost for maintaining or repairing their clients' equipment regardless of the number or severity of failures occurring. From a research perspective, contributions to uncertainty management in service contracting are scarce. There is a lack of methods which allow to evaluate uncertainties and to quantitatively assess their impact on business. However, business analytics provides ample opportunities for reducing uncertainty - by supporting its quantitative measurement and by assisting to identify cause-effect relationships among influencing factors. Based on the use-case of maintenance services, we investigate how analytics can contribute to a quantitative assessment of uncertainty. Subsequently, we develop strategies to improve the design of service contracts in order to reduce providers' exposure to uncertainty or to mitigate its business impact. Linking capabilities in data analytics to decision sciences, our research contributes to improving contract design and to promote service-based value propositions in the industrial sector.

### 4 - Field Technician Scheduling 4.0

*Johannes Kunze von Bischoffshausen, Michael Vössing*

Technician scheduling problems have been studied in operations research for decades. Classical modeling of field technician scheduling problems includes different types of jobs (repair, maintenance, installation) and different technician skills. Furthermore, classical optimization models take different time windows where jobs have to be started, different locations of jobs, as well as prioritization into account.

With the rise of the Industrial Internet of Things and Industry 4.0, more and more sensor data is captured from assets which need to be repaired, maintained or installed by field service technicians. Predictive maintenance, using sensor data for forecasting required maintenance of assets, is becoming one of the major fields of application in Industry 4.0.

However, little research has been conducted on how to leverage predictive maintenance for field technician scheduling. We propose a research agenda towards leveraging the potential of Industry 4.0 for field service technician scheduling. This requires implementing an analytics IT-infrastructure for integrating and analyzing high-frequency sensor data, predictive analytics for forecasting required maintenance actions, and prescriptive analytics for determining maintenance schedules. This will enable industrial firms to increase the availability of their assets, decrease maintenance costs, and implement new business models such as full-service contracts.

*Christian Tilk*

Many governments worldwide have imposed hours of service regulations for truck drivers to avoid fatigue-related accidents. These regulations ensure that break and rest periods are regularly taken, i.e. they define a minimum amount of break and rest times for truck drivers as well as a maximum driving time between two break or rest periods. Transport companies have to take this into account and plan the routes and schedules of their truck drivers simultaneously. This problem is called vehicle routing and truck driver scheduling problem (VRTDSP). Recently, Goel and Irnich (2014) presented the first exact approach for the VRTDSP. They include hours of service regulations in a vehicle routing problem with time windows and use a branch-and-price algorithm to solve it. Here, we present a sophisticated branch-and-price-and-cut algorithm for the VRTDSP that is based on the parameter-free auxiliary network and the resource extension functions (REFs) defined by Goel and Irnich (2014). We will extend their labeling algorithm by means of defining backward REFs in order to build a bidirectional labeling. To obtain feasible routes a non-trivial merge procedure is presented. The concept of using a dynamic halfway point and the ng-route relaxation (Baldacci et al., 2011) is used to speed up the solution process. In Addition, different families of known valid inequalities are used to further strengthen the LP-relaxation of the master program. We will present a detailed computational study to analyze the impact of the different techniques.

### 2 - A regulatory impact analysis of hours of service regulations in Europe

*Asvin Goel*

This contribution studies how different hours of service regulations impact road freight transport in the European Union. In Europe, hours of service of truck drivers must comply with Regulation (EC) No 561/2006 and the respective national implementations of Directive 2002/15/EC. Throughout the European Union, the night work provisions of the directive are differently implemented into national law. This contribution presents an adjustable model and solution approach that can be used to generate routes and schedules complying with these differing implementations. The approach is evaluated within an exact approach for the vehicle routing and truck driver scheduling problem. A regulatory impact analysis is conducted comparing the impact on costs and road safety of the routes and schedules generated by the proposed approach considering the different regulations in Europe.

### 3 - Truck Driver Shift Scheduling in Vehicle Routing with Time-Dependent Service Costs

*Alexander Kleff, Tobias Pröger*

Our research is motivated by a real-life problem which shares the characteristics of three enhancements of the classical vehicle routing problem. The first enhancement is to expect a time-dependent service cost function for every delivery order as input, instead of hard or (still less general) soft time windows. Such a function reflects how inopportune the delivery is at a certain point in time. Vehicle routing with time-dependent service costs was first introduced as the vehicle routing problem with general time windows. While goods can be delivered anytime in our case, drivers cannot work an arbitrarily long time. Hence drivers alternate in shifts, i.e., every vehicle can be used multiple times per day. For a planning horizon of one day, usually three shifts and thus three trips are planned. This is the second enhancement, usually called the vehicle routing problem with multiple trips. As the third enhancement, we are given a maximum shift duration as input. So each trip must not exceed this duration. Also, drivers have to respect break and rest rules. For instance, the regulation 561/2006 of the European Union states that after driving for at most 4.5 hours, drivers have to take a break of at least 45 minutes. This constitutes (a variant of) the vehicle routing and truck driver scheduling problem. The combination of these three enhancements has not been studied before. In our talk, we will focus on the truck driver scheduling part of the problem.

## ■ WC-21

Wednesday, 13:30-15:00 - Seminarraum 405/406

### Hours of Service Regulations

Stream: Logistics, Routing and Location Planning

Chair: *Asvin Goel*

#### 1 - Branch-and-price-and-cut for the vehicle routing and truck driver scheduling problem

## Wednesday, 15:30-16:15

### ■ WD-02

Wednesday, 15:30-16:15 - Hörsaal 1

#### Semi-Plenary Miettinen

Stream: Semi-Plenaries

Chair: *Kathrin Klamroth*

##### 1 - Advantages of Interactive Multiobjective Optimization Methods Demonstrated with NAUTILUS Navigator enabling Navigation without Trading-Off

*Kaisa Miettinen*

Multiobjective optimization is needed because most real-life optimization problems contain more than one objective function. The goal in multiobjective optimization is to find the best possible solution in the presence of several, conflicting objective functions. Using mathematical tools we can define a set of Pareto optimal solutions where none of the objective function values can be improved without impairing at least one of the others. However, we need additional preference information from a domain expert, a decision maker, to find the most preferred Pareto optimal solution as the final solution to be implemented. Multiobjective optimization methods can be classified according to the role of the decision maker in the solution process. We concentrate on interactive methods, where the decision maker takes actively part in the solution process and directs the search for the final solution according to her/his desires and hopes. This enables the decision maker to gain insight about the interdependencies of the conflicting objectives and learn about one's own preferences. Typically, interactive methods deal with Pareto optimal solutions only and the decision maker must trade-off to be able to move from one Pareto optimal solution to another. To avoid this need of trading-off, a family of NAUTILUS methods has been proposed. In NAUTILUS, the interactive solution process begins from an inferior solution and the decision maker can gain improvement in all objective functions and direct the solution process until (s)he reaches the set of Pareto optimal solutions. In this way, (s)he can move more freely without anchoring around any solution. We introduce a new method called NAUTILUS Navigator which incorporates the NAUTILUS philosophy with elements of the Pareto Navigator method. With NAUTILUS Navigator, the decision maker can navigate in real time towards the set of Pareto optimal solutions and continuously see how the region of objective function values that are reachable without trading-off shrinks. The distance to the set of Pareto optimal solutions is also shown. Thanks to the graphical user interface, the information is available in an understandable form. The decision maker can provide preference information to direct the movement as desirable aspiration levels and bounds that are not to be exceeded. The decision maker can change the navigation direction at any time and even go backwards if needed. The NAUTILUS Navigator method is also applicable to computationally expensive problems where function evaluations are time-consuming. We demonstrate how the method can be applied with a three-objective optimization problem for identifying the improvements that can be carried out in the auxiliary services of a power plant in order to enhance its efficiency, taking into account energy savings and economic criteria.

### ■ WD-03

Wednesday, 15:30-16:15 - Hörsaal 2

#### Semi-Plenary Woeginger

Stream: Semi-Plenaries

Chair: *Michael Juenger*

##### 1 - New answers to old questions on the TSP

*Gerhard J. Woeginger*

k-OPT is one of the most popular local search heuristics for the Travelling Salesman Problem (TSP). k-OPT tries to improve a suboptimal tour by removing k of the edges and by reconnecting the resulting tour pieces into a new tour by inserting k new edges. In the talk, I will mainly concentrate on the question whether a given tour is a local optimum for k-OPT (where k is some fixed, small number), and I will present a fine-grained complexity analysis of this problem.

### ■ WD-04

Wednesday, 15:30-16:15 - Hörsaal 3

#### Semi-Plenary Marklund

Stream: Semi-Plenaries

Chair: *Stefan Minner*

##### 1 - Sustainable Supply Chain Inventory Control

*Johan Marklund*

The increasing environmental awareness drives a growing interest among companies for more sustainable supply chain operations. One important challenge is to reduce transportation emissions while minimizing total inventory and transportation costs for multi-stage systems. In this talk different aspects of this challenge are considered for distribution systems where a central warehouse replenishes a number of local warehouses or retailers. Particularly, we present a multi-echelon inventory control model incorporating volume dependent freight costs and emissions, shipment consolidation, and intermodal transport options. To emphasize the importance of a multi-stage perspective, we also present results from a simulation study of a Scandinavian spare parts provider with frequent use of emergency deliveries. It illustrates that applying a multi-echelon inventory control method can significantly reduce total inventories and transport emissions while improving fulfillment of target fill-rates.

### ■ WD-06

Wednesday, 15:30-16:15 - Hörsaal 5

#### Semi-Plenary GOR Unternehmenspreis

Stream: Semi-Plenaries

Chair: *Alf Kimms*

**Wednesday, 16:30-18:00****■ WE-02**

Wednesday, 16:30-18:00 - Hörsaal 1

**Polyhedral Combinatorics (i)**

Stream: Discrete and Integer Optimization

Chair: *Matthias Walter*Chair: *Anja Fischer***1 - Dantzig-Wolfe Reformulations for the Stable Set Problem***Jonas Witt, Marco Lübbecke*

Dantzig-Wolfe reformulation of an integer program convexifies a subset of the constraints, which yields an extended formulation with a potentially stronger linear programming (LP) relaxation than the original formulation. This paper is part of an endeavor to understand the strength of such a reformulation in general.

We investigate the strength of Dantzig-Wolfe reformulations of the classical edge formulation for the maximum weighted stable set problem. Since every constraint in this model corresponds to an edge of the underlying graph, a Dantzig-Wolfe reformulation consists of choosing a subgraph and convexifying all constraints corresponding to edges of this subgraph. We characterize Dantzig-Wolfe reformulations not yielding a stronger LP relaxation (than the edge formulation) as reformulations where this subgraph is bipartite. Furthermore, we analyze the structure of (critical) facet-graphs (i.e., graphs that define facets) of the stable set polytope and present a characterization of Dantzig-Wolfe reformulations with the strongest possible LP relaxation as reformulations where the chosen subgraph contains all odd holes (and 3-cliques).

These results motivate the investigation of Dantzig-Wolfe reformulations obtained by (heuristically) searching for edges that are contained in an odd hole (or a 3-clique) and convexifying the corresponding constraints. We discuss algorithms to calculate such reformulations and present computational results using the generic branch-price-and-cut solver GCG. In particular, we examine the reformulations in relation to other reformulations computed by GCG and draw a comparison to solving the initial integer programming formulation with the branch-and-cut solver SCIP.

**2 - A New Hierarchy for Solving Polynomial Matroid Optimisation Problems***Anja Fischer, Frank Fischer, Thomas S. McCormick*

In this talk we consider polynomial matroid optimisation problems. We present a new hierarchy for solving these problems. This approach is based on polyhedral results for special polynomial matroid optimisation problems with some non-linear monomials that satisfy certain up- and downward completeness conditions. The monomials are linearised by introducing new variables. Extending results of Edmonds we present a complete description for the linearised polytope. Indeed, apart from the standard linearisation in this case, one only needs appropriately strengthened rank inequalities. The separation problem of these inequalities reduces to a submodular function minimisation problem. We derive a hierarchy for these kinds of optimisation problems by enlarging the degree of the monomials in each step. Finally, we present some preliminary computational results and give suggestions for future work.

**3 - Investigating Polyhedra by Oracles***Matthias Walter, Volker Kaibel*

The software framework IPO (Investigating Polyhedra by Oracles) is presented which allows to analyze polyhedra that are given only implicitly by an optimization oracle. The motivation comes from polyhedral combinatorics, where the oracle can easily be provided by a mixed-integer-programming solver. IPO detects a full system of equations and some facets of the implicitly given polyhedron with exact arithmetic. The facets are produced in such a way that they are helpful in optimizing a given objective function. This is in contrast to usual convex-hull algorithms which produce the entire description of a polyhedron, but run out of resources for small dimensions already. Thus, IPO can typically handle larger dimensions.

In the talk we will briefly discuss how IPO actually works, followed by a demonstration of its capabilities. For this we consider short computational studies, namely dimension analysis of MIPLIB 2.0, facet-detection for matching polytopes with one quadratic objective term and adjacency statistics for TSP polytopes.

IPO is available at <http://polyhedra-oracles.bitbucket.org/>**■ WE-03**

Wednesday, 16:30-18:00 - Hörsaal 2

**Combinatorial Optimization II**

Stream: Discrete and Integer Optimization

Chair: *John Martinovic***1 - Two-Stage Cutting Stock Problem with Due Dates***Zeynep Sezer, Ibrahim Muter*

In this study, we consider a scheduling extension for the two-stage cutting stock problem with the integration of order due dates. The two-stage cutting stock problem arises when technical restrictions inhibit demanded items to be cut from stock rolls directly and hence require the cutting process to be done in two subsequent stages. The mathematical model proposed for the due date extension aims to determine a cutting plan which not only minimizes the number of stock rolls used but also reduces tardiness and earliness costs incurred. Preliminary results have shown that the modeling approach used is capable of overcoming difficulties caused by the dependencies between stages.

**2 - On-line Algorithms for Controlling Palletizers***Frank Gurski, Jochen Rethmann, Egon Wanke*

We consider the FIFO Stack-Up problem which arises in delivery industry, where bins have to be stacked-up from conveyor belts onto pallets. Given are  $k$  sequences of labeled bins and a positive integer  $p$ . The goal is to stack-up the bins by iteratively removing the first bin of one of the  $k$  sequences and put it onto a pallet located at one of  $p$  stack-up places. Each of these pallets has to contain bins of only one label, bins of different labels have to be placed on different pallets. After all bins of one label have been removed from the given sequences, the corresponding stack-up place becomes available for a pallet of bins of another label. The FIFO Stack-Up problem is computational intractable (Gurski, Rethmann, Wanke, MMOR 2016). In this paper we consider on-line algorithms for instances where we only know the first  $c$  bins of every sequence instead of the complete sequences. We implemented our algorithms and could show that for randomly generated instances our best approaches leads only 15 per cent more stack-up places than optimal off-line solutions. On the other hand we could show worst case examples which show an arbitrary large competitive factor when comparing our on-line solutions with optimal solutions.

**3 - On the Solution of Generalized Spectrum Allocation Problems***John Martinovic, Eduard Jorswieck, Guntram Scheithauer*

We consider a spectrum aggregation based spectrum allocation problem (SAP) for wireless communications: find the maximum number of secondary users whose bandwidth requirements can be satisfied by aggregating (parts of) given spectrum holes. In the classical form, this optimization problem turns out to share a common structure with the one-dimensional skiving stock problem (SSP). However, in practice, the spectrum aggregation is usually restricted by hardware limitations, such as filter technologies, and the capability of controlling interference. These additional constraints separate the considered problem from an ordinary SSP, and represent a new challenge in the field of discrete optimization. This presentation provides a general introduction to the relations between the SSP and the SAP. Furthermore, we will discuss, how practical meaningful extensions of the classical SAP can be tackled from a mathematical point of view. As a main contribution, we exploit some important problem-specific properties to derive tailored solution techniques.

**■ WE-04**

Wednesday, 16:30-18:00 - Hörsaal 3

**Energy Management in the Steel Industry**

Stream: Energy and Environment

Chair: *Magnus Fröhling*

### 1 - A real world application for the „Balanced Blocks Relocation Problem" in the steel industry

Jan Necil, Felix Brandt, Eric Ebermann, Stefan Nickel

In these days the price of steel has come under pressure due to Asian low-cost providers. For that reason producing best quality particularly efficient is more important than ever for steel producers in high-cost countries like Germany. In our contribution we provide a short insight into our long-term cooperation with DILLINGER, one of the biggest heavy plate producers in the world. We set a special focus on the well-known Blocks-Relocation-Problem and its application in the steel industry. The basic problem deals with the removal of blocks out of storage in a given sequence. In the storage the blocks are stored in stacks. The objective is to minimize the amount of restacking. This problem also occurs for example at sea container terminals. Additionally we show how we expand the basic formulation to a Balanced-Blocks-Relocation-Problem. In our case the model is applied to a heavy plate store of the Heavy Fabrication Division at DILLINGER. Here several plates are buffered in stacks before they are processed at the customer's request. The primary objective is to maximize (balance) the utilization of the downstream production with as little restacking operations as possible. For this purpose, we developed an efficient solution method for the Balanced-Blocks-Relocation-Problem, which is currently evaluated in the operations at DILLINGER. The system's task is on the one hand to support the crane operators, who execute the restacking operations. On the other hand, it provides the opportunity to simulate future situations at the heavy plate store for several weeks to gain planning insights. In our contribution we motivate the problem and provide an efficient solution method.

### 2 - Operations-Research in integrated steel industry: Use cases from DILLINGER

Eric Ebermann, Heike Busch, Jan Necil, Stefan Nickel

Nowadays European steel makers face high competitive pressure. High quality is demanded at a low price. The strong competition leads to continuous increasing cost pressure, especially due to overproduction at the global market, price dumping or the current plans of the EU regarding CO<sub>2</sub>-emissions trading. This situation makes the application of Operations Research in the steel production indispensable. The company DILLINGER, one of the biggest heavy plate producers in the world, takes a leading role in this field of innovation. For this purpose a team of experts with the task of applying optimization methods to production was created. It focuses on the development, implementation and transfer of problem-oriented solution methods to operations. In our contribution we provide a broad review of the use cases at DILLINGER that were tackled with OR techniques such as mixed integer optimization, genetic algorithms or local search methods. Additionally we explain fundamental challenges and best practices. Furthermore we describe problems of the future and potential solutions.

### 3 - Estimating greenhouse gas emissions of European steel suppliers

Andreas Schiessl, Patrick Breun, Konrad Zimmer, Frank Schultmann

In times of fast growing stakeholder interest in sustainability, the ecological and social performance of industrial companies and its products is gaining increasing importance. In particular, the emission of greenhouse gases (GHG) in the automotive industry has come to the forefront of public and governmental attention. This changeover represents a major challenge especially for the purchasing section, as up to 75% of the value adding process of a car takes place in the upstream supply chain. Faced by the regulatory factors of the use phase of cars and the thirst for innovation, OEMs are constantly developing new technological solutions. Looking at a selected product of a German car manufacturer, a hybrid design of steel, aluminum and CFRP has been applied with the aim of reducing weight and emissions. From a lifecycle perspective, steel - 40-45% of the overall car weight - remains to be the leading critical material in terms of GHG emissions in the upstream supply chain. In order to integrate CO<sub>2</sub> as decision criteria - along with quality and cost - in a supplier selection process in the long run, this research develops a combined-LCA model which is suitable for a supplier specific assessment of the environmental performance of steel manufacturers without the need for confidential internal data. By using a technology-driven bottom-up approach, the internal material and energy flows corresponding to the on-site production facilities are at first calculated by means of a carbon balance. The site-specific reported CO<sub>2</sub> emissions are then allocated to the relevant facilities via a top-down approach, while traded intermediate products are explicitly incorporated in order to adjust the system boundaries. The model is applied to 22 case studies in the European steel industry.

## ■ WE-05

Wednesday, 16:30-18:00 - Hörsaal 4

### Coordination Games

Stream: Game Theory and Experimental Economics

Chair: Thomas Neumann

#### 1 - An experimental investigation of supplier-retailer contracts

Claudia Keser, Giuseppe Paleologo, Emmanuel Peterlé

We examine individual decisions of supply-chain partners in a newsvendor setting. We conduct a laboratory experiment to compare the performance of the standard wholesale price contract to the theoretically efficient buyback contract. Findings indicate that introducing a buyback component to supply-chain contracts does not significantly increase efficiency. This is principally due to the fact that suppliers set relatively low buyback prices. Consistent with theoretical predictions, we find that retailers' ordering decisions are negatively related to the wholesale price and positively related to the buyback price. This suggests that buyback contracts could potentially lead to an increase in the supply-chain efficiency, provided that the incentives associated to such contracts are well-understood and correctly implemented by the suppliers.

#### 2 - Vasopressin increases human risky cooperative behavior

Bodo Vogt, Claudia Brunnlieb

The history of mankind is an epic of cooperation, which is ubiquitous across societies and increasing in scale. Much human cooperation occurs where it is risky to cooperate for mutual benefit, because successful cooperation depends on sufficient level of cooperation by others. Here we show that arginine vasopressin (AVP), a neuropeptide that mediates complex mammalian social behaviors such as pair bonding, social recognition and aggression, causally increases human's willingness to engage in risky, mutually beneficial cooperation. In two double-blind experiments, male participants received either AVP or placebo intranasally and made decisions with financial consequences in the "stag hunt" cooperation game (example of an coordination game). AVP increases humans' willingness to cooperate. That increase is not due to an increase in the general willingness to bear risks or to altruistically help others. Using functional brain imaging, we show that when subjects make the risky stag choice, AVP down-regulates the BOLD-signal in the left dorsolateral prefrontal cortex (dlPFC), a risk-integration region, and increases the left dlPFC functional connectivity with the ventral pallidum, an AVP receptor-rich region previously associated with AVP-mediated social reward processing in mammals. These findings show a novel causal role for AVP in social approach behavior in humans, as established by animal research.

#### 3 - Equilibrium selection in coordination games: An experimental study of the role of higher order beliefs in strategic decisions

Thomas Neumann, Bodo Vogt

The equilibrium selection in games with multiple equilibria, such as coordination games, depends on the beliefs about other player's behavior, meaning that the outcome of the players' depends on their expectations about the other player's behavior. Regarding the uncertainty involved in coordination games, a player's risk attitude might (also) influence the equilibrium behavior. With this study, we address the question whether risk attitude or beliefs of players explain the strategic choices in 2x2 coordination games. In a laboratory experiment we elicit the risk attitudes by using lottery choices. Furthermore, using a quadratic scoring rule, subjects' first order beliefs about the choice of the opponent are elicited directly. Additionally, we elicited the players' higher order beliefs and analyzed if there was any influence of the depth of thinking on the strategic decision. Our data show that participants' behavior is not explained by risk attitude, but rather is it best response to their stated first order beliefs. Higher order beliefs follow different patterns which are in most cases in contrast to Bayesian updating.

## ■ WE-06

Wednesday, 16:30-18:00 - Hörsaal 5

### GOR Dissertation Prize

Stream: Prize Awards

Chair: *Anita Schöbel*

### 1 - Solving Network Design Problems - with an Application to the Optimal Expansion of Railway Infrastructure

*Andreas Börmann*

In this work, we develop solution approaches for large-scale network design problems, focussing on both theoretical and algorithmic aspects. Our motivation is a task set by our industry partner Deutsche Bahn AG, which is to study an optimal capacity expansion for the lines in the German railway network until 2030. We develop a specialized decomposition approach for this multi-period network design problem that works by splitting up the problem along the timescale. The approach allows both for a quick heuristic with high-quality results and for an exact method via a suitable embedding into a Benders decomposition framework. To treat the huge size of the networks under consideration, we develop an exact spacial decomposition based on graph aggregation. The idea is to solve the problem over a coarse network representation obtained via a clustering of the nodes to components and to refine it iteratively where needed. The result is a cutting-plane method whose cutting-planes dominate the Benders feasibility cuts. Both ideas are easily transferrable to more general network design contexts. We conduct a comprehensive computational case study for the German railway network showing the excellent performance of the approaches in terms of solution time and quality compared to standard methods.

### 2 - On- and Offline Scheduling of Bidirectional Traffic

*Elisabeth Lübbecke*

The thesis provides theoretical and practical insights related to bidirectional traffic on a stretch containing bottleneck segments. On a bottleneck segment, concurrent traveling of vehicles in opposite direction is restricted. Single tracks in railway planning are a typical example. This work is motivated by and considers in particular the ship traffic at the Kiel Canal which connects the North and Baltic Seas and is operated bidirectionally. Since ships register their travel requests only on short notice, the planning of the Canal's ship traffic additionally features the requirement that decisions must be adapted online.

Characteristic for bidirectional traffic is that vehicles moving in the same direction can enter a tight lane sequentially with relatively little headway while vehicles in opposite direction must wait until the whole lane is empty again. With a compact scheduling model that accurately accounts for this specialty, a detailed analysis of the problem's off- and online complexity is accomplished. To deal with open gaps between upper and lower bounds on optimal competitive ratios in the online setting, a new concept for its approximation is presented. Finally, combining the scheduling perspective with a dynamic routing approach yields a performant heuristic to tackle complex ship traffic control instances.

### 3 - Integrated Segmentation of Supply and Demand with Service Differentiation

*Benedikt Schulte*

The presented research addresses the integrated segmentation of supply and demand with service differentiation by means of service-level menus. To this end, it establishes a joint perspective on the market side - that is, prices and service levels - and the operations side - that is, the inventory management policy and the corresponding parameters. This joint perspective comprises analyzing when the introduction of a service-level menu increases profits over those of a single undifferentiated offering and how to design optimal service-level menus. Surprisingly, in many cases service differentiation does not increase profits significantly. One way to interpret this finding is that differentiating customers based on service levels alone is a weak differentiation lever only, that is, the price differences between offerings with differing service levels need to be small in order to prevent customers from switching to offerings with lower prices and service levels. Therefore, successful price differentiation requires service differentiation's being supported by presence of additional conditions or measures (e.g., pricing restrictions or further differentiation levers). Indeed, it is possible to show that service differentiation can significantly increase profits if the company experiences pricing restrictions.

## ■ WE-07

Wednesday, 16:30-18:00 - Hörsaal 6

### Game Theory and Incentives

Stream: Game Theory and Experimental Economics

Chair: *Stephan Schwartz*

#### 1 - Sourcing Innovation: Public and Private Feedback in Contests

*Jochen Schlapp*

Contests, in which contestants compete for a prize offered by a contest holder, have become a popular way to source innovation. Despite great interest from the academic community, many important managerial aspects of contests have received very little formal inquiry. The most important of these is feedback from the contest holder to the contestants while the contest unfolds. This paper sets out to establish a comprehensive understanding of how to give feedback in a contest by answering the questions of when to give feedback and when not to give feedback and which type of feedback to give, public (which all solvers can observe) or private (which only the concerned party can observe). We find that feedback will not affect the behavior of competing problem solvers unless the contest holder credibly pre-commits to a truthful feedback policy. We then set up a framework that reduces the feedback decision to a pair of conceptual questions. First: Is the contest's ultimate objective to increase average quality or to find the best solution? Second: How uncertain are outcomes for the solvers? We show that no feedback or public feedback generally dominate private feedback. However, if the host is interested exclusively in the best performance and if the contest displays large uncertainties, private feedback is optimal.

#### 2 - A Dynamic Game Theory Model for Dispute Resolution between Public and Private sector Partners in PPPs

*Mohammad Rajabi, Jamal Ouenniche*

Public-Private Partnerships (PPPs) is a widely used modality that provides many benefits for the public sector in the delivery of public services. Negotiation is one of the most important business activities in the whole life cycle of PPP projects. The long-term nature of the projects and the rapid changes in the market lead to numerous conflicts between the public sector representative and the private sector partner during the execution stages. In this research, we consider the negotiation process after awarding the contract to the selected private sector partner as a non-cooperative dynamic game of complete information and propose an analytical model to assist with decision making. Our analysis is concerned with resolving economic disputes and provides an appropriate strategy for overcoming financial problems and preventing delays in project's implementation. Managerial guidelines and solutions to prevent conflicts and improve the administrative process are proposed.

#### 3 - Designing Inspector Rosters with Optimal Strategies

*Stephan Schwartz, Thomas Schlechte, Elmar Swarat*

We consider a network security game where the aim is to allocate limited inspection resources to defend a network against potential attackers. This is typically modeled in a game theoretic framework where the inspectors commit to a control strategy while the attackers strike accordingly. Indeed, these optimal inspectors' strategies are widely regarded as superior to standard scheduling strategies, such as uniform random inspections. A crucial step towards practical use however, is to transform the control strategy into feasible inspectors' duty rosters, which are subject to various legal constraints. Due to the complexity of the game theoretic problem an integrated game theoretic duty rostering approach is impracticable.

In this work, we examine how key aspects of the rostering problem can be introduced to the game theoretic model and how the optimal control strategy can be converted into feasible duty rosters for the inspectors. While the game theoretic optimization is formulated as a flow problem in a control graph, we impose several constraints regarding the working hours as arc capacities. We present a clustering approach to identify pairs of duty types and operation days with a similar traffic load. This leads to a reduced game theoretic model formulation as well as to an increase of the degree of freedom for the subsequent rostering problem. Furthermore, we present a randomized rounding algorithm to transform the mixed control strategy into a set of duties for the planning horizon.

The research is motivated by a cooperation with the Federal Office for Goods Transport which is responsible for enforcing a truck toll on German motorways. We apply the presented methods to real world scenarios to demonstrate the potential of the proposed approaches.

## ■ WE-08

Wednesday, 16:30-18:00 - Seminarraum 101/103

### Network Design for Distribution Logistics

Stream: Logistics, Routing and Location Planning

Chair: Tobias Buer

Chair: Michaela Thulke

#### 1 - Competitive Service Network Design when Demand is Sensitive to Congestion

Pratibha Pratibha, Cornelia Schoen

In this paper we present a market-oriented service network design model where the seller's problem is to determine the number of facilities, their locations, their service capacity, and their service level such that overall profit is maximized. Our model explicitly takes into account customer choice of a facility as a function of typical choice determinants, such as travel distance and congestion delays (endogenously impacted by the seller's decision), as well as other exogenous factors such as price level and product variety. We relax the assumption of many related works that the service provider has discretion about the assignment of customers to facilities; rather, we allow customers to self-select based on their preference for facility attributes according to an attraction-based choice model. Furthermore, we do not only capture the effect that congestion has on demand but also the reciprocal impact of demand on congestion and service level, respectively, by modeling each facility as an M/G/1 queue where service capacity is a decision variable. The resulting model is a nonlinear mixed-integer problem; however, we show that problem can be linearized and solved exactly by introducing several new continuous variables and "big M" constraints. We test the performance of our approach in an extensive computational experiment. A case study of locating new convenience stores in Heidelberg, Germany illustrates real-world applicability of the model using empirical market research data. The problem arises in a number of other applications, in particular in service shop industries such as restaurants, retailers, etc. but surprisingly, profit maximization under customer choice behavior has been hardly considered as an objective in the literature.

#### 2 - Planning of mobile deconsolidation points in grocery retail logistics

Michaela Thulke, Thomas Volling

Mobile deconsolidation points are an innovative approach towards reorganized structures in distribution logistics. The underlying principle is the following: goods are consolidated to full truck loads in central warehouses to be shipped to strategically placed deconsolidation points. From these points the goods are transshipped to their final destination. As opposed to traditional transshipment concepts, mobile deconsolidation points have minimal infrastructure requirements and can be dynamically (re-)located to match transportation demands. Mobile deconsolidation points therefore combine the efficiency of hub-and-spoke networks with the flexibility of direct shipments. This makes them a particularly interesting candidate solution to tackle the challenges in grocery retail logistics: high cost pressure, pronounced demand variability and rigid traffic and delivery constraints.

We identify the potential of mobile deconsolidation points in grocery retail logistics under different operating conditions and specify implications for distribution planning. We discuss the interdependencies between locating deconsolidation points and vehicle routing, and develop an integrated planning approach. The approach is illustrated based on the case of a German grocery retailer. To conclude, we point out issues for future research.

#### 3 - Optimization Based Network Design in UPS Turkey

Gozde Merve Demirci, Aylin Baykan, Yaprak Dolgun, Fadime Üney-Yüksektepe

United Parcel Service (UPS) was established as a package delivery company in 1907 by Jim Casey, which provides specialized transportation and logistics services expanded to Turkey in 1988. UPS Turkey

has 23 hubs and more than 260 branch offices and authorized service suppliers.

In order to satisfy customers' requirements, company needs to arrange their network design and planning thereby, massive demands, coming from customers, can be easily transported. Since UPS Turkey has not changed its network design since 2008, it becomes hard to fulfill the increasing demand and to manage the distribution efficiently. Thus, in this project network redesign problem of UPS Turkey is studied by analyzing the current network and customer demands.

In this study, a mathematical programming model is developed to solve the proposed problem efficiently. By using the data obtained from the company, the network is reorganized while satisfying limitations and optimizing its objectives. The developed model is solved by using GAMS software and CPLEX solver. The results are compared with the current situation and different scenario analysis are performed.

## ■ WE-09

Wednesday, 16:30-18:00 - Seminarraum 105

### Finance III

Stream: Finance

Chair: Michal Fendek

#### 1 - Long-run UIP Holds even in the Short Run

Fabian Ackermann, Karl Schmedders, Walter Pohl

Understanding the relationship between interest rates and exchange rates has proven to be surprisingly difficult. One of the oldest theories in finance, uncovered interest parity, provides an attractive explanation for the behavior of exchange rates. Exchange rates should adjust to equalize returns on loans across countries. This means that high interest-rate currencies will depreciate relative to low interest-rate currencies. Unfortunately, empirical research has not been kind to this hypothesis. Not only do exchange rates not adjust in the direction predicted by the theory, but in some samples they move in the wrong direction.

Long-run UIP, like any long-run financial hypothesis, is difficult to test. To get sufficient statistical power to resolve the question would require many non-overlapping intervals, and financial time series are generally not long enough to provide a clear test for longer maturities. Estimates for the effect of interest rates on exchange rates have proven to be rather unstable. Evidence suggests that interest rates themselves has a unit root, which makes statistical inference difficult.

In this paper we introduce a short-run test of long-run UIP. This test sidesteps the econometric difficulties mentioned above, and provides unambiguous evidence in favor of long-run UIP. UIP can be reinterpreted as a contemporaneous relationship between returns. This relationship can be tested at a monthly frequency, which sidesteps the non-overlapping intervals problem. Returns do not suffer from a unit root, and the estimates have the same sign as predicted by UIP in most subperiods. Interestingly, the support for UIP is stronger after the financial crisis than before.

#### 2 - Bond Mutual Funds and Complex Investments

Markus Natter, Martin Rohleder, Dominik Schulte, Marco Wilkens

We are the first to analyze bond mutual funds' permission and use of complex investment practices such as derivatives, restricted securities and securities lending. Based on unique regulatory information from the SEC's N-SAR filings, we show that most complex investments do not affect fund performance or risk. However, interest rate futures (IRF) are harmful to bond funds. Bond funds engaging in IRF (45.8% of all bond funds) underperform nonusers by economically meaningful 51 basis point p.a. (alpha). Further results reveal that bond funds employ IRF for speculation as they increase funds' exposure towards interest rate risk.

#### 3 - Quantitative analysis the degree of concentration in the Slovak banking sector

Eleonora Fendekova, Michal Fendek

A competitive environment is an attribute of virtually every aspect of economic relations. A characteristic feature of the market environment is dynamism, a constant change which is induced by an effort to reach maximum competitiveness. Functioning of a market mechanism is conditioned by the existence of a good market conditions for which respecting the conditions of economic competition is necessary. An effective functioning of the economy in a developed and globalized market environment requires many system measures which relate

to the principles of the effective functioning of the market mechanism. An idea that the market mechanism is functioning automatically and effectively is as mistaken as it is dangerous. One of the most important attributes of the failure-free and, most of all, harmonically developing economic system, is a government guaranteed protection of the principles of economic competition. A violation of these principles, which is of course economically advantageous for the participants and in some cases may even be socially efficient in short-term, is clearly a negative trend from the point of view of long-term development of the economy. Violation of competition principles due to the high concentration of the activities on the supply side in the hands of a limited number of the subjects is highly hazardous particularly in the banking sector, whose activities determine basically all aspects of social and economic life. An objective of this article is to review the competition environment and analyze the degree of concentration in the banking sector of the Slovak republic using the quantitative methods and models of the microeconomic analysis.

## ■ WE-11

Wednesday, 16:30-18:00 - Seminarraum 110

### Sequencing and Scheduling

Stream: Production and Operations Management

Chair: *Tobias Kreiter*

#### 1 - Solving job-shop problems with blocking constraints by simulated annealing

*Julia Lange, Frank Werner*

Solving job-shop scheduling problems with blocking constraints constitutes a theoretical foundation of many applications in production planning and logistics. In order to decrease inventory costs, just-in-time production systems aim to use no storage capacities and in railway transportation a no-store restriction is directly implied. In both cases a product or a train blocks the machine or the track it is assigned to until the next machine or track is idle. These planning situations can be interpreted as job-shop scheduling problems, where a certain set of jobs with given release and due dates has to visit machines in a predefined order without storage capacity in between. Since customer satisfaction is one of the main goals in many industries, a schedule (i.e. the starting times of the jobs on the machines), which minimizes the total tardiness of all jobs, is to be determined. A job-shop scheduling problem with a total tardiness objective is NP-hard even without blocking constraints. Computational experiments on MIP formulations of the given optimization problem documented high computation times for very small instances. This implies a necessity to develop heuristic approach to generate near-optimal feasible solutions. Blocking constraints cause an additional difficulty in defining a feasible schedule based on a given solution encoding. A procedure how to always generate a feasible schedule is developed. With this, a simulated annealing is implemented using different priority rules to determine initial solutions and applying several neighborhood structures and cooling schemes. The results obtained with different settings of the algorithm are presented and compared by means of total tardiness values and computation time.

#### 2 - Optimization models for vehicle planning in the pre-production phase

*Tilak Raj Singh*

Pre-production vehicles are used to facilitate extensive testing of new components and its interfaces. Despite the success of software and simulation model based testing, physical prototypes are still a necessary step in automobile development. Full vehicle tests are required to capture overall system performance (e.g. cabin noise, mileage) and technical feasibility among different individual systems. Contrary to current automobile series production process, the degree of automation during pre-production stage is minimal, thus, manual and specialized process incurs significant cost and time on every vehicle produced.

Total number of vehicle required during pre-production is mainly governed by the predefined set of tests, test schedule and components configuration rules. Task is to find minimal number of vehicle configurations such that each test is executed in pre-specified time frame. The problem turns out to be a large scale optimization problem as number of possible vehicle configurations are huge. We use column generation using Lagrange relaxation to solve large scale optimization models. First results are demonstrated from industrial size problem instance.

### 3 - Sequencing mixed-model multi-level assembly lines

*Tobias Kreiter, Ulrich Pferschy*

In a wide range of industries product variety increased drastically over the last decade. Manufacturers face the challenge of providing a growing variety at a low cost. Thus, the traditional production schemes with large batch sizes are transformed by decreasing lot sizes and mixed-model assembly lines. The extreme point of this development will be a one-piece flow model where the production plan considers each single product individually. However, different products (variants) differ in their configuration and thus may also differ significantly in the induced workload. To reach a production plan where the work intensity of all products lies within a limited range, manufacturers with a heterogeneous portfolio have to outsource some assembly steps to pre-levels. In this way, a constant speed on the main assembly line should be reached by shifting variances in work intensity to pre-production lines. These can be organized in one or several levels. As for lean manufacturing systems only very small intermediate buffers exist (if any), the temporal distribution of workload in these pre-levels is strongly affected by the production sequence of the main line. Therefore smoothing pre-level workload needs to be respected in sequencing the main assembly line. Considering the real-world application of assembling engines and gearboxes in a large Austrian manufacturer, a MILP-model for optimizing sequences in a mixed-model multi-level assembly line production system is presented. Taking additional constraints from the real-world situation into account requires non-trivial extensions of the main MILP-model. Our modelling approach and obtained results compare favorably to those of the advanced planning system that is currently in use by the company.

## ■ WE-12

Wednesday, 16:30-18:00 - Seminarraum 202

### Approximate Dynamic Programming: Methods and Applications

Stream: Metaheuristics

Chair: *Marlin Wolf Ulmer*

#### 1 - Anticipation for Stochastic Inventory Routing in Bike Sharing Systems

*Jan Brinkmann, Marlin Wolf Ulmer, Dirk Christian Mattfeld*

Bike Sharing Systems (BSS) allow individual and sustainable urban mobility. They have been implemented in a considerable number of cities around the globe. In BSS, customers can rent and return bikes ad hoc at stations and at each time of the day. To allow a reliable usage, system operators have to realize sufficient fill levels, i.e., numbers of bikes and free bike racks, at each station. Due to a spatio-temporal variation of requests, determining sufficient fill levels is a challenging task. To adapt fill levels, transport vehicles relocate bikes between stations. To combine inventory management and vehicle routing, we model these processes as a stochastic Inventory Routing Problem (IRP). To solve the IRP, we introduce a Rollout algorithm (RO) that simulates the near future to anticipate future requests and reveals stations' urgencies for relocations. Decisions regarding inventory management are made by simulating the consequences of possible decisions. Decisions regarding routing are made by approximating the number of failed requests in the near future for each station. We evaluate the RO in computational studies on real world data based on Vienna's BSS "CityBike Wien". A myopic Short-term Relocation strategy (STR) serves as benchmark heuristic. It does not anticipate future requests and makes use of static safety buffers to balance bikes and free bike racks. Results point out that for the RO a suitable time span for simulating the near future needs to be determined to reveal decisions' consequences and stations' urgencies. If a suitable time span is chosen, RO outperforms STR by far.

#### 2 - Multi-Period Technician Scheduling with Experience-based Service Times and Stochastic Customers

*Barrett Thomas, Xi Chen, Mike Hewitt*

This talk introduces the multi-period technician scheduling problem with experience-based service times and stochastic customers. In the problem, a manager must assign tasks of different types that are revealed at the start of each day to technicians who must complete the tasks that same day. As a technician gains experience with a type of task, the time that it takes to serve future tasks of that type is reduced (often referred to as experiential learning). As such, while the problem could be modeled as a single-period problem (i.e. focusing solely

on the current day's tasks), we instead choose to model it as a multi-period problem and thus capture that daily decisions should recognize the long-term effects of learning. Specifically, we model the problem as a Markov decision process and introduce an approximate dynamic programming-based solution approach. The model can be adapted to handle cases of worker attrition and new task types. The solution approach relies on an approximation of the cost-to-go that uses forecasts of the next day's assignments for each technician and the resulting estimated time it will take to service those assignments given current period decisions. We also introduce a value-function approximation that uses each worker's experience on each task as a basis function. Using an extensive computational study, we demonstrate the value of our approaches versus a myopic solution approach that views the problem as a single-period problem.

### 3 - Risk-Averse Approximate Dynamic Programming for Dynamic Vehicle Routing

Marlin Wolf Ulmer, Stefan Voss

In the field of dynamic vehicle routing, the importance to integrate stochastic information about possible future events in current decision making increases. Integration is achieved by anticipatory solution approaches, often based on approximate dynamic programming (ADP). ADP methods estimate the expected mean values of future outcomes. In many cases, decision makers are risk-averse, meaning that they avoid "risky" decisions with highly volatile outcomes. Current ADP methods in the field of dynamic vehicle routing are not able to integrate risk-aversion. In this paper, we adapt a recently proposed ADP method explicitly considering risk-aversion to a dynamic vehicle routing problem with stochastic requests. We analyze how risk-aversion impacts solutions' quality and variance. We show that a mild risk-aversion may even improve the risk-neutral objective.

## ■ WE-13

Wednesday, 16:30-18:00 - Seminarraum 204

### Optimal Control for Supply Chain and Operations Management I

Stream: Control Theory and Continuous Optimization

Chair: Dmitry Ivanov

#### 1 - Serious Strategy for the Video Games Industry: Pay-to-Play vs. Free-to-Play

Andrea Seidl, Jonathan Caulkins, Richard Hartl, Peter M. Kort

The paper analyzes two business models commonly used in the video games industry. We consider the situation when the game producer starts out with a subscription-based model but then considers when, if ever, to switch to a free-to-play business model which price discriminates between typical users, who play free, and heavy users who pay for acquiring extra features.

We find that over time, the qualitative behavior of prices and associated number of users is the same, while advertising behaves oppositely. Switching from subscription to free-to-play induces a considerable increase in advertising efforts. If the costs of switching business models are considerable and/or the "addictiveness" of the game is low, a history-dependent solution emerges, where different initial situations result in different long-run business strategies. On the other hand, an intermediate level of game addictiveness can lead to thresholds in which the firm can be indifferent between two distinct initial business strategies, even though both converge to the same strategy in the long run and produce the same overall profit.

#### 2 - Ripple Effect in the Supply Chain: Control Perspective

Dmitry Ivanov

In light of low-frequency-high-impact disruptions, ripple effect has been recently introduced into academic literature on supply chain management. Ripple effect in the supply chain results from disruption propagation from the initial disruption point into the supply, production, and distribution networks. While optimization modelling dominates this research field, the potential of control theoretic modelling still remains underexplored. The objective of this study is to reveal research gaps that can be closed with the help of control theoretic.

First, recent literature on both optimization and control theoretic modelling is analysed. Second, a control theoretic model for multi-stage supply chain design with consideration of capacity disruptions and experimental results are presented. Based on both literature analysis and modelling example, managerial insights and future research areas are derived in regard to optimal control theory application to ripple effect analysis in the supply chain. The paper is concluded by summarizing the most important insights and outlining future research agenda.

### 3 - Optimal Control of Stochastic Hybrid Systems under Regime Switches, Impulsiveness and Delay, in Finance, Economics and Nature

Gerhard-Wilhelm Weber, Emel Savku, Nadi Serhan Aydin, Busra Temocin, A. Sevtap Selcuk Kestel

We contribute to modern OR by hybrid, e.g., mixed continuous-discrete dynamics of stochastic differential equations with jumps and to its optimal control. These hybrid systems allow for the representation of random regime switches or paradigm shifts, and are of growing importance in economics, finance, science and engineering. We introduce some new approaches to this area of stochastic optimal control and present results. One is analytical and bases on the finding of optimality conditions and, in certain cases, closed-form solutions. We further discuss aspects of differences in information, given by delay or insider information. The presentation ends with a conclusion and an outlook to future studies.

## ■ WE-14

Wednesday, 16:30-18:00 - Seminarraum 206

### MCDM Applications and Case Studies

Stream: Decision Theory and Multiple Criteria Decision Making

Chair: Erdem Aksakal

#### 1 - The older, the better..!? - Benchmarking Quality Efficiency of time-consuming Whisky Production using DEA

Magnus Richter

According to experts production/distillation of scotch single malt whisky has reached sufficiently high levels of technical efficiency within the last years, especially concerning the most cost-intensive factors such as, e.g., labor. Because of the low/zero prices of the remaining factors as e.g. barley, water and air, (partial) inefficiencies concerning their input will hardly decrease distilleries' profits as well. Thus enhancing quality of single malt whisky nowadays seems more important. In the paper a quality adjusted, two-model DEA approach, invented by Sherman and Zhu (2006) and modified by Shimshak and Lenard (2007), is applied on empirical data of scotch whisky to identify quality leaders. Quality is incorporated in the model by considering distilleries as quality producing DMUs whose outputs are qualitatively captured via the rating scheme of MURRAY'S Whisky Bible. Its categories Nose, Taste, Finish and Balance, each of them ranging from 0-25 Points, serve as output criteria so the distillation technology can be checked for quality-benchmarks. An input-oriented envelopment model with constant returns to scale (CCR) is run using the software MaxDEABasic64. The results, inter alia, show that exceeding the legal minimum of storage time of 3 years considerably decreases quality efficiency of whisky production, that is, the contribution of time to whisky quality has been systematically overestimated within theory and practice. Hence, an appropriate reduction of storage time seems advisable; this insight, by the way, seems to be a persuasive explanation for the use of so called non-age-statements, which are increasingly used by many distilleries as a replacement for explicit age declarations which are traditionally printed on whisky bottles (e. g. "12 years old").

#### 2 - Multi Criteria Decision Making Methods for Ranking the Countries with respect to the Logistic Performance Index

Nimet Yapıcı Pehlivan, Aynur Şahin

Logistics and transportation play an important role in international trade relations. The international trade is one of the complicated interactions between people, firms, and organizations, whereas supply chains cross countries and regions. Competitiveness of the countries on a global scale is affected by unsatisfactory systems of transportation, logistics and trade-related infrastructure. The Logistics Performance Index is an interactive benchmarking tool and it measures



logistics performance of countries according to six indicators which are customs, infrastructure, international shipments, logistics quality&competence, tracking&tracing and timeliness. The LPI was first published by World Bank in 2007 and then repeated in 2010, 2012, 2014. The LPI is performed a worldwide online survey on responsible of companies based on 5-point numerical scale to evaluate logistics performance of countries around the world. The LPI consists of two parts: International LPI and domestic LPI. The World Bank' LPI and its indicators help to understand and identify the challenges and opportunities of the countries that they face in their performance on trade logistics and what they can do to improve their performance. The LPI allows leaders in government, business, and civil society to better evaluate the competitive advantage created by good logistics and to understand the relative importance of different interventions. The aim of this study is to propose multiple criteria decision making (MCDM) methods for ranking the countries with respect to the logistic performance index regarding six indicators. Furthermore, we will analyze and compare the ranking results with respect to the considered MCDM methods and Principal Component Analysis (PCA) prepared by World Bank.

### 3 - Building decision making models through Conceptual-Constraints: multi-scale process model implementations

Canan Dombayci, Antonio Espuña

The integration of decision-making procedures typically assigned to different hierarchical levels in a production system (strategic, tactical, and operational) requires the use of complex multi-scale mathematical models and high computational efforts, in addition to the need of an extensive management of data and knowledge within the production system. The aim of the study is to propose a comprehensive solution for this integration problem through the use of Conceptual-Constraints. This study presents a methodology based on a model in a domain ontology and proposes the use of generalized concepts to develop tailor-made decision making models, created according to the introduced data. Different decision making formulations are reviewed, accordingly, Conceptual-Constraints for material balances are determined. This work shows how the Conceptual-Constraints can be used when the quality of information is changed, enables multi-scale implementations.

Financial support from the Spanish Ministry of Economy and Competitiveness and the European Regional Development Fund, both funding the Project ECOCIS (DPI2013-48243-C2-1-R), from the 'AGAUR', and from the Generalitat de Catalunya (2014-SGR-1092-CEPEiMA) is fully appreciated.

### 4 - Marina destination selection under Analytic Network Process: A Case from Turkey

Erdem Aksakal

As being a part of the tourism activity, marine tourism getting much more popular in nowadays. On the other hand, as a part of it, marinas play a significant role in marine tourism. With the dictionary meaning, marina is a dock or basin for yachts and small boat. From this point, if you have yacht or a boat you need some facilities in marinas as refueling, washing and repair facilities, stores, restaurants and etc. According to the definition and significant part of marine tourism, marinas can be described as destinations. In recent years, as considering the dimensions of the tourism activities, multi criteria decision making methods have been applied in evaluation studies. This study aims to propose an approach for the selection of a marina destination with using Analytic Network Process. Criteria were taken as Transportation, Service, Accessibility, Facilities, Local Culture, Entertainment. The weights of the evaluation criteria were determined by pair-wise comparison and Analytic Network Process is used to make a prioritization among six different destinations over Turkey.

## ■ WE-15

Wednesday, 16:30-18:00 - Seminarraum 305

### Complex scheduling problems (i)

Stream: Project Management and Scheduling

Chair: Sigrid Knust

### 1 - Decomposition algorithms for synchronous flow shop problems with additional resources and setup times

Sigrid Knust, Stefan Waldherr

We present decomposition algorithms for synchronous flow shop problems with additional resources and setup times. In such an environment, jobs are moved from one machine to the next by an unpaced synchronous transportation system, which implies that the processing is organized in synchronized cycles. This means that in each cycle the current jobs start at the same time on the corresponding machines and after processing have to wait until the last job is finished. Afterwards, all jobs are moved to the next machine simultaneously. During processing, each job needs an additional resource and setup times have to be taken into account when changing from one resource to another. The goal is to find a production sequence of the jobs as well as a feasible assignment of resources to the jobs such that the total production time (makespan) is minimized. We propose two decomposition approaches dealing with the two subproblems of job scheduling and resource assignment hierarchically. Both approaches are computationally evaluated and compared.

### 2 - A shortest path algorithm for routing of triple crossover cranes

Lennart Zey, Dirk Briskorn

In recent years the need for efficient processes in sea ports has grown due to the increasing volume of maritime transport. With the help of Automated Stacking Cranes (ASCs) which store and relocate containers in container yards the corresponding storage processes can be improved significantly concerning time, costs and productivity. We consider a system of three cooperating stacking cranes working jointly on a single yard block. Here one large crane can cross two small cranes of equal height and width that cannot cross each other. We present an algorithm solving the problem of determining conflict free schedules that minimize the makespan under the assumption that assignment of container transports to cranes and the sequences of transports assigned to the same crane are predetermined. Since cranes cannot work independent from each other it remains to create collision free schedules deciding right of way when operations of two cranes cannot be processed simultaneously. We propose both, a mixed integer programming model as well as a representation of the problem in a three dimensional graphical model. The latter enables us to construct an acyclic graph to determine schedules represented by shortest paths between distinguished nodes by means of dynamic programming. Further, we provide a deeper insight into the handling of detours in the graphical model as well as computational results comparing both models.

### 3 - Scheduling of Vehicles with Handover Relations at Transshipment Terminals

Dirk Briskorn, Malte Fliedner, Martin Tschöke

We consider a generic problem arising when coordinating deliveries and collections at a transshipment terminal. A set of vehicles and a set of doors given, we distinguish between problem settings where each vehicle can be docked only once, each vehicle can be docked multiple times at the same door, and each vehicle can be docked multiple times at different doors. We have a set of handover relations meaning that one vehicle delivers goods to be picked up by another. For such a handover relation to be satisfied the second vehicle must be docked at some point of time after the first arrival of the first vehicle. We consider settings where storing goods is allowed and settings where this is not the case and investigate the computational complexity of finding a feasible docking policy.

## ■ WE-16

Wednesday, 16:30-18:00 - Seminarraum 308

### Data Analytics

Stream: Health Care Management

Chair: Sebastian Kohl

### 1 - Towards a Process Analysis Tool: Goodness-of-Fit Tests on clinical processes

Tobias Weller, Maria Maleshkova, Martin Wagner, Lena-Marie Ternes, Hannes Kennigott

Everyday work in clinics and hospitals generates a lot of data such as the runtime of tasks, diagnosis, and the occurrence of complications during the treatment of patients. Due to the increased use of sensors and the continuous digitalization, the volume of electronic health records is estimated to grow worldwide from 500 petabytes in 2012 to 25,000 petabytes by 2020. This growing data volume cannot be handled without the help of computers. Commonly, clustering algorithms are used to group similar data elements according to specific characteristics. However, they do not provide information about the distribution of the data. To this end, we use Goodness-of-Fit Tests to determine the distribution of health records. This allows for making more precise statements over health data, which cannot be done just by using clustering. This information can help to plan processes and make statements over the frequency of observations. As a use-case scenario, we have 1,690 process instances from the Heidelberg University Hospital. The process instances describe the perioperative process (e.g. what tasks are performed before, during and after surgery). Data points such as the duration of each task, blood losses and complications are given. We refined the process instances and uploaded them into a Semantic MediaWiki. Based on this data, for the purpose of determining the distribution among health records, we perform Chi-Square Goodness-of-Fit Tests, which is a widely used statistic test to assess the distribution for certain observations. We use the correlation coefficient to evaluate the fitness of the distribution to the observed data. To perform the Chi-Square Goodness-of-Fit Tests, we implemented an extension to Semantic MediaWiki that performs the tests and presents the results.

**2 - Pitfalls in Hypothesis Testing: Sensitization and Solution to Multiple Testing Problems**

*Christina Bartenschlager, Jens Brunner*

Deciding on more than one null hypothesis based upon the same data set can lead to an inflation of the type I error rate. Therefore, statisticians have developed an abundance of methods for such multiple testing problems over the last century. Our study on current publications in Management Science emphasizes that multiple testing methods are relatively rarely applied, despite the significant relevance for empirical research. The multitude of available multiple testing methods may deter researchers from employing them altogether, we suppose. Hence we provide guidance to researchers by means of a user-oriented systematization. As the identified ranges of application are suitable with different multiple comparisons simulations are meant to show the adequate multiple test within each profile.

**3 - Exploring the Accuracy of Data Envelopment Models using Monte Carlo Simulated Production Data**

*Sebastian Kohl, Jens Brunner*

Data Envelopment Analysis (DEA) is one of the most popular benchmarking techniques to assess the efficiency of companies or organizations. It identifies "best practices" and compares the performance of all companies to the resulting best practice frontier. Areas of application are among others, banking, healthcare, education, transportation or agriculture. Since its invention in 1978, lots of different model developments have emerged. Yet it is unclear, which of those models delivers the most accurate results and should therefore be the first choice for the computation of efficiency. To overcome this gap, we try to develop a benchmark based on generated data that combines multiple performance indicators and delivers robust results on the performance of different DEA models.

**■ WE-18**

*Wednesday, 16:30-18:00 - Seminarraum 401/402*

**Collaborative Transportation Planning II (i)**

Stream: Logistics, Routing and Location Planning

Chair: *Mario Ziebuhr*

Chair: *Kristian Schopka*

**1 - Bundle generation in combinatorial transportation auctions**

*Margaretha Gansterer, Richard Hartl*

In combinatorial transportation auctions auctioneers have to decide on the bundling of requests such that attractive packages can be offered to the carriers. From a practical point of view, offering all possible bundles is not manageable, since the number of bundles grows exponentially with the number of requests that is traded. Thus, the auctioneer has to limit the number of bundles to a reasonable amount. The offered bundles should be attractive to the carriers in order to yield profitable allocations of requests. Furthermore, carriers are typically not willing to reveal sensitive information like their available capacities. Thus, the auctioneer has to deal with feasibility of offered bundles under incomplete information. We present a combinatorial auction framework, with a bundling strategy that guarantees to achieve feasible assignments of bundles to bidders without having them to reveal their capacity restrictions. We use two heuristic methods to generate attractive bundles: (i) k-means and (ii) an genetic algorithms-based approach. We compare the performance to the results that we achieve if all possible bundles are offered to the carriers. We demonstrate that by using appropriate heuristics, the number of offered bundles can be significantly reduced, while the solution quality shows only little deviation from the benchmark results.

**2 - Non-cooperative pricing decisions in Site-Dependent Vehicle Routing Problems**

*Silvia Schwarze*

We consider the situation of independent, heterogeneous carriers within a transport system and apply the Vehicle Pricing Game (VPG), a non-cooperative game approach that reflects the competition among the actors. In this setting, each vehicle chooses a price for carrying out transport services and receives a payoff dependent on the assigned tasks. In order to determine the tour assignment and the respective pay-offs, a Vehicle Routing Problem (VRP) including vehicle-dependent routing costs is solved. Heterogeneity is given by varying vehicle characteristics, like vehicle equipment or driver qualification. These characteristics may in turn restrict a vehicle's ability to carry out a particular service, which leads to site-dependencies in the corresponding VRP and affects a vehicle's competitiveness. Given the competition among vehicles, it is investigated which price a vehicle should choose to maximize its own profit and to which extend heterogeneity of vehicles influences this decision. For the case of a two-player ring network game, the existence of pure-strategy equilibria is discussed and the full set of pure-strategy equilibria is identified. To that end, the competition ratio and the acceptance ratio are introduced that provide bounds on prices such that competitiveness is maintained. It is shown that the uniqueness of the higher-skilled vehicle's payoff is guaranteed in a two-player ring network even for multiple equilibria. Experimental results are provided for general networks including the option for penalizing long tours.

**3 - Transportation Planning with different Forwarding Limitations**

*Mario Ziebuhr, Herbert Kopfer*

In competitive transportation markets freight forwarders are confronted with thin margins and high demand fluctuations. In these markets forwarders try to improve their planning situation by using external resources besides their own resources. These external resources might belong to closely related long term carriers, common carriers or cooperating forwarders within horizontal coalitions. In recent publications, it is assumed that there are requests which have to be fulfilled by certain resources due to contractual obligations. These requests are denoted as compulsory requests. The contribution of this publication is to identify the increase in transportation costs caused by considering different kinds of compulsory requests simultaneously. To analyze the impact of compulsory requests, an existing column generation-based heuristic with two solution strategies for handling compulsory requests is applied.

**■ WE-19**

*Wednesday, 16:30-18:00 - Seminarraum 403*

**Resource Scheduling in Public Transportation (i)**

Stream: Traffic and Passenger Transportation

Chair: *Natalia Kliewer*

## 1 - The Electric Vehicle Scheduling Problem - A study on modelling approaches for charging a vehicle's battery

*Nils Olsen, Natalia Kliewer*

The Electric Vehicle Scheduling Problem (E-VSP) extends the traditional Vehicle Scheduling Problem by restricting the range of the deployed vehicles and considering the possibility to recharge a vehicle's battery at some charging stations. One fundamental aspect of electro mobility which hasn't attract much attention within existing solution approaches for the E-VSP is the manner and functionality of recharging the electric vehicles' batteries.

In practice, the majority of deployed electric vehicles hold a lithium ion battery to store energy to power their engines. One crucial property of this battery type due to the internal processes which occur during a charging process is the aspect that a lithium ion accumulator can be recharged in a short time frame to a specific energy charge smaller than the maximum battery capacity (e.g. 60%) but the time needed to fully recharge a lithium ion accumulator is a multiple of that timeframe. Within existing solution methods for the E-VSP these nonlinearities haven't been considered sufficiently yet.

We present different modelling approaches for the charging process of electric vehicles to consider the nonlinearities constituted previously and propose methods for computing resulting charging times. Following this, we analyse the impact of the different modelling approaches on the resulting vehicle schedules using heuristic solution methods. For that purpose, we solve different real-world instances of the E-VSP.

## 2 - A Sequential Approach for Vehicle and Crew Scheduling Problem in Public Bus Transportation

*Hande Öztöp, Uğur Eliiyi, Deniz Türsel Eliiyi, Levent Kandiller*

In this study, we consider a real life vehicle and crew scheduling problem of a public bus transportation authority. The objective is to determine the optimal number of different types of vehicles and crew members (drivers) with a minimum cost, to cover a given set of trips and corresponding deadheads regarding working and spread time limitations of drivers. There are sequence-dependent setup times between trips corresponding to deadheads, and sequence-dependent setup times between tasks. Each trip must be covered by a single vehicle and at least one driver, and the trips can be divided into smaller trip segments. Each task, containing of a trip segment or a deadhead resulting from vehicle-trip assignments, must be performed by a single vehicle and single driver. The trips can require different types of vehicles requiring different crew capabilities. Therefore, several vehicle and crew classes exist in the problem. As the problem cannot be solved within reasonable time limits, a sequential approach is proposed where the vehicle and crew scheduling problems are solved successively. We formulate binary programming models for each subproblem. In crew scheduling, we consider only the processing times of tasks in the working time, in order to avoid including additional sequence variables. We develop an iterative valid inequality generation scheme for eliminating task sequences that exceed the total working time when setup times are included. The performance of the developed solution methodology is investigated through an experimentation and the numerical results are reported. The results show that our solution procedure is quite efficient for instances with up to 120 trips.

## 3 - A framework for agent based simulation of demand responsive transport systems.

*Joschka Bischoff, Ninja Soeffker, Michal Maciejewski*

Demand responsive transport (DRT), such as shared mini busses, have become a viable form of public transport mainly in rural areas in recent years. In contrast to ordinary schedule-based services, DRT systems come in many different shapes and forms and are usually customised to the environment they operate in. E.g., they might be restricted to certain user groups or only operate in specific areas or with a specific fixed terminus. With advances in ICT and the possibility of driverless operations in the future, DRT systems may become an attractive additional mode also in urban and inter-urban transport. This brings the necessity to assess and evaluate DRT services and possible business models, with transport simulations being one possible way. This study introduces a framework for an extensible, open source shared minibus service simulation. Based on the agent based transport simulation MATSim and its existing DVRP extension, the extension provides DRT services as an additional mode to the synthetic population of a MATSim scenario. The module allows assigning vehicles to groups according to different dispatch algorithms shaped to the actual use case. In a first case study, a DRT system complements ordinary public transport and car infrastructure on the heavily used commuter relation between Braunschweig

and Wolfsburg. During peak times, average travel times per traveller over all modes between the two cities can be reduced by 5 minutes using a fleet of 50 8-seat-vehicles. In a second case study, a DRT system is used to shuttle passengers in an area with non-optimal public transport access to the train station in Braunschweig. With given capacity constraints, the optimizer has to decide which customers to serve in order to achieve an on-time arrival for passengers.

## 4 - Column generation for Airline Crew Rostering: Practical considerations in a production system

*Hamid Kharraziha, Andreas Westerlund*

Jeppesen's crew rostering optimizer is today used by around 40 airlines to produce monthly schedules for their flight crew. The optimizer allows the user to configure various kinds of business logic and it solves monthly schedules for problem instances with above 20k crewmembers and 100k activities.

In this presentation we will start by defining the rostering problem in general. Then we will describe the column generation framework that is used to deal with it. Finally we will look at the specific problem of having an efficient fixing process in the presence of high degree of symmetry.

## ■ WE-20

*Wednesday, 16:30-18:00 - Seminarraum 404*

## Forecasting

Stream: Business Analytics and Forecasting

Chair: *Sven F. Crone*

## 1 - Modelling of water use patterns in the Rajasthan Province of India

*Shankar Venkatagiri, Shashank Garg, Krishna Sundar Diatha*

The Government of India frequently conducts surveys of its minor irrigation schemes, each of which covers a culturable command area (CCA) of up to 2000 hectares. This paper examines the data from a pilot water census of Rajasthan, which is India's largest province by area; a large part of the province experiences extreme heat. The pilot study conducted in 2013 was a landmark exercise: it was executed with the help of handheld devices, completed within two months, and generated over 1 million records across 10 districts within the province. One of the primary objectives of this pilot study was to demonstrate the feasibility of using low-cost mobile devices for a future census of minor irrigation schemes. We use analytical techniques to make inferences on water availability patterns, and the capacity of different villages to sustain multiple crop cycles within the region. By combining information from multiple sources, we show how the demographic composition of the villages is influenced by the availability of water.

## 2 - Statistics instead of stopover - Range predictions for electric vehicles

*Christian Kluge, Stefan Schuster, Diana Sellner*

Electric vehicles can play a central role in today's efforts to reduce CO2 emission and slow down the climate change. However, despite various technological advancements and public support, consumers react cautiously to current offers of the electrical market. As surveys show, two of the most important reasons against the purchase or use of an electric vehicle are its short range and long charging times. In the project "E-WALD - Elektromobilität Bayerischer Wald", we develop mathematical models to predict the range of electric vehicles by estimating the electrical power consumption (EPC) along possible routes. Based on the EPC forecasts the range is calculated and visualized by a range polygon on navigation map which is represented on a tablet computer in the car. The models are based on data that is constantly collected by cars that operate within a commercial car fleet. The collected data are prepared in two different ways, an energy-based and a distance-based way. Both datasets are modeled with same methods, a linear model, an additive model and a fully nonparametric model. To fit the different models, ordinary least squares regression as well as linear median regression are applied. The other models are fitted by modern machine learning algorithms: the additive model is fitted by a boosting algorithm and the fully nonparametric model is fitted by support vector regression. The models are compared by the mean absolute error. Our research findings show that data preparation is more influential than

the chosen model here. Based on these results, additionally a data-driven adaptive adjustment is developed to adapt the prediction to real EPCs while driving. By reliable range prediction for electric vehicles, a higher confidence in electric mobility is achieved.

### 3 - Don't Correct and Combine Judgmental Forecast

*Sebastian Blanc*

Corporate decision making and planning usually rely on the quality of forecasts. Since expert knowledge is considered relevant in many predictive tasks, many forecasts are generated -although often supported by a forecast support system - by human experts. In the literature, it is regularly found that forecast correction or combination can improve the accuracy of judgmental forecasts. Forecast correction techniques such as Theil's method are motivated by the fact that judgmental forecast are regularly biased. Systematic biases are identified using past forecasts and corresponding errors and are then removed from future forecasts. In contrast, forecast combination aims at reducing error by combining a judgmental forecast with an alternative forecast, for instance a model-based prediction. Since both techniques have been shown to improve accuracy, an obvious extension might be to include a corrected forecast instead of the original judgmental forecast in a combination. In this work, we study the theoretical properties of this approach. We show that applying both techniques can be expected to result in asymptotical accuracy improvements only under very narrow conditions. Consequently, we recommend applying only one of the two techniques since potential advantages in terms of bias-reduction will be easily negated by increased error variance resulting from the complexity of the approach.

### 4 - Improving the forecasting accuracy of two-step segmentation models

*Friederike Paetz*

The estimation of consumer preferences with conjoint-choice models is well-established. In particular, the use of Hierarchical Bayesian (HB) models, which estimate consumers' individual preferences is nowadays state-of-the-art in theory and practice. However, the knowledge of consumer preferences on a less disaggregated level, like segment-level, is crucial especially for demand predictions of products, that could not be customized individually. Clustering individual HB data to achieve segment-level preferences is known to be inappropriate, since two-step segmentation approaches generally lead to worse forecasting accuracy in comparison to one-step segmentation approaches, e.g., Latent Class models. But, may the inclusion of different concomitant variables into the cluster process of individual conjoint-choice data relax the disadvantage of two-step approaches w.r.t. forecasting accuracy? To answer this question, we used an empirical data set and estimated a Latent Class Multinomial Logit (MNL) model as well as an HB model. Subsequently, we clustered the HB data with and without the consideration of different concomitant variables, e.g., demographic and psychographic variables. Finally, we compared the forecasting accuracy of all model types. While demographic variables, e.g., age or gender, showed only tiny effects, psychographic variables turned out to heavily improve forecasting accuracy of two-step segmentation models. In particular, two-step approaches, that consider psychographic variables within the clustering process, showed a forecasting accuracy just as well as the one of one-step approaches.

stored best possible for future retrievals. Algorithms for these problems have to decide which items of a family should be used at which point in the retrieval sequence and where incoming and blocking items should be located. Heuristics and metaheuristics for the loading and the unloading problem are proposed and compared to strategies which are currently used in the warehouse of a German company producing work plates. Computational results are presented for a large data set of randomly generated instances according to the setting in the warehouse and two smaller real-world data sets.

### 2 - Window Fill Rate in a Two-echelon Exchangeable-Item Repair-System

*Michael Dreyfuss, Yahel Giat*

The fill rate service measure describes the proportion of customers who commence service immediately upon arrival to an inventory system. Since, however, customers will usually tolerate a certain wait time, managers should consider the window fill rate in lieu of the fill rate. That is, they should maximize the probability that a customer is served within the tolerable wait time. In this paper, we develop approximation formulas for the window fill rate in a two-echelon, exchangeable-item repair system in which the top echelon is a central depot and the bottom echelon comprises multiple locations. To estimate the accuracy of the formulas, we compare the formula-derived window fill rate values with simulation-derived window fill rate values.

### 3 - Extension of the A\*-Algorithm for Puzzle-Based Storage Systems Problems

*Altan Yalcin, Achim Koberstein, Kai-Oliver Schocke*

A Puzzle-Based Storage Systems (PBS) consists of a grid with an initial occupancy of densely stored unit-loads. Each item represents an obstacle that is movable. Escort locations (empty slots) are used to enable movement. System performance depends upon suitable use of escort locations. Previous work has focused on analytical studies of single-load systems with and one or two escort locations. An optimal solution method for systems with more than two escort locations has not been provided yet. We present a single-load motion planning algorithm with multiple escort locations that provides optimal solutions with a minimum number of moves. The algorithm is based on the A\* algorithm that is a best-first search and uses heuristics to guide its search. We consider only a fraction of available escort locations and show the admissibility of this approach. Within that framework, we developed three heuristics by problem relaxation and solution criticism. Computational experiments compare the heuristics' performance on randomly generated problem instances and show how well the algorithm performs for different configurations. Our contribution provides an algorithm that enables further research in the field of PBS such as retrieval time analysis studies of PBS with multiple escort locations or PBS with multiple I/O points.

## ■ WE-21

Wednesday, 16:30-18:00 - Seminarraum 405/406

### Storage Systems Optimization

Stream: Logistics, Routing and Location Planning

Chair: *Achim Koberstein*

#### 1 - Loading and unloading strategies for a stacking problem with item families

*Sven Boge*

In this work, we consider the process of loading and unloading items in a warehouse. The items are stored in stacks and moved by a crane. Each item is associated with a family indicating the main attribute (type) of the item. For a given subsequence of these item families it has to be decided which item of each requested family shall be unloaded from the warehouse using the least possible number of crane moves to save time and cost. Related to this, incoming items shall be

**Thursday, 9:00-10:30****■ TA-02**

Thursday, 9:00-10:30 - Hörsaal 1

**Mixed Integer and Linear Programming Software (i)**

Stream: Discrete and Integer Optimization

Chair: *Sven Wiese***1 - Parallelization of the FICO Xpress Optimizer***Timo Berthold*

We will present some of the recent MIP advances in the FICO Xpress Optimizer, with an emphasis on its new parallelization concept. To achieve reasonable speedups from parallelization, a high workload of the available computational resources is a natural precondition. At the same time, reproducibility and reliability are key requirements for mathematical optimization software. Thus, parallel LP-based branch-and-bound algorithms are expected to be fully deterministic. The resulting synchronization latencies render the goal of a satisfying workload a challenge of its own. We address this challenge by following a partial information approach and separating the concepts of simultaneous tasks and independent threads from each other. Our computational results indicate that this leads to a much higher CPU workload and thereby to an improved scaling on modern high-performance CPUs. As an added value, the solution path that the Optimizer takes is not only deterministic in a fixed environment, but on top of that platform- and, to a certain extent, thread-independent.

**2 - Recent improvements in the CPLEX LP solver***Bo Jensen, Roland Wunderling*

Being able to efficiently solve Linear Programs has been taken for granted in the past decade, prompting practitioners to build larger and larger problem instances. In recognition of this fact, the CPLEX LP solver has been enhanced. We will discuss those developments and provide a detailed performance evaluation of their effect.

**3 - Gurobi - Performance Improvements and New Features***Michael Winkler*

We will give an overview on performance improvements for different problem classes and introduces new features of the current Gurobi release. In detail, we focus on some special tricks and ideas that are the foundation for these improvements.

**■ TA-03**

Thursday, 9:00-10:30 - Hörsaal 2

**Selected Topics of Discrete Optimization**

Stream: Discrete and Integer Optimization

Chair: *Christoph Buchheim***1 - Low-rank/sparse-inverse decomposition***Jon Lee, Victor Fuentes*

The problem of decomposing an input matrix as the sum of a sparse matrix and a low-rank matrix is a well-studied problem, with application to the problem of identifying a sparse Gaussian model obscured by low-dimensional noise. An accepted convex approximation is achieved by replacing the sparsity function by the one-norm and the rank function with the nuclear norm, and taking an appropriate weighted combination. Solution methods for the convex approximation range from semidefinite programming to first-order methods such as the alternating direction method of multipliers. On the mathematical side, a recovery theorem gives nice conditions for the solution of the approximation to recover a pre-specified solution.

We take this prior work as our point of departure, but we look instead at decomposing an input matrix as the sum of a matrix having a sparse inverse and a low-rank matrix. One example of interest is where the

input matrix is a sample covariance matrix of Gaussian random variables, and the sparse matrix we seek is the underlying "precision matrix" (whose zero pattern captures the pairwise conditional independence structure, conditioning on all other random variables). Without a natural convex approximation, we cannot expect the techniques and mathematics for the ordinary version of the problem to carry over. Instead, employing the Woodbury matrix identity, we establish a sound framework for attacking the problem. Our numerical results demonstrate that: (i) our proposed methodology is useful and practical, (ii) our method leads to a useful means for generating good test instances for other algorithms that we are developing for the problem, and (iii) a direct generalization of the recovery theorem for the ordinary version of the problem is unlikely.

**2 - Optimal division of the electoral districts for the single-member constituency system***Keisuke Hotta*

Japanese electoral system is now flawed. The vote-value disparity between constituencies for the Diet is large. The Supreme Court of Japan decided that the disparity in the value of votes for the House of Representatives was "in a state of unconstitutionality". Because of this, the Diet has tried to rectify the zoning of electoral districts to narrow the vote-value gap. Up to now the Diet also has reduced the number of seats. The number of members for the single-seat constituency for the House of Representatives is 289 in 2016. It has been 295 from 2013 to 2016, and 300 from 1994 to 2013. The planning process for the redistricting of the single-seat constituency in Japan is as follows. First, all seats are apportioned to 47 prefectures in proportion to the population. Then, each electoral district is decided in each prefecture. This research shows the optimal division of the electoral districts, and the limit of the disparity ratio by using 0-1 IP model for the apportionment problem and the 47 redistricting problems, respectively. The population of the 2015 Census is used. The current cities are used as a component comprising electoral district. The optimization model is based on Hotta&Nemoto(2003). The limit of the disparity ratio is 1.653 for the apportionment problem, and 1.962 for the districting problems.

**3 - Robust Assignments with Vulnerable Edges***Dennis Michaels, Viktor Bindewald, David Adjashvili*

The assignment problem under uncertainty is considered. The uncertainty is given by a set of vulnerable edges from the underlying bipartite graph. Each vulnerable edge defines a failure scenario that, if emerges, leads to a deletion of the corresponding edge. For a given cost function, the task is to determine a cost-minimal subset of edges that contains, for every scenario, an assignment covering all nodes of the graph. In this talk, hardness results and approximation algorithms for this type of robust assignment problems are presented.

**■ TA-04**

Thursday, 9:00-10:30 - Hörsaal 3

**Applications in energy modelling**

Stream: Energy and Environment

Chair: *Michael Zipf***1 - BEAM-ME: Acceleration Strategies for Energy System Models***Frederik Fiand, Michael Bussieck*

BEAM-ME is a project funded by the German Federal Ministry for Economic Affairs and Energy (BMWi) and addresses the need for new and improved solution approaches for energy system models. The project unites various partners with complementary expertise from the fields of algorithms, computing and application development. The considered problems result in large-scale LPs that are computationally intractable for state-of-the-art solvers. Hence, new solution approaches combining decomposition methods, algorithm development and high performance computing are developed. We provide an overview on the large variety of challenges we are facing within this project, present current solutions approaches and provide first results.

**2 - Linear reformulations of the unit commitment problem**

*Kerstin Daechert, Christoph Weber*

The well-known unit commitment problem determines the cost-optimal commitment of power plants to meet an exogenously given demand while taking certain constraints like maximum capacity, minimum stable operation limit, minimum operation time, minimum downtime etc. into account. The problem is classically formulated as a mixed-integer linear program. However, when applying this MIP model to real-world instances like the German or European electricity market with a one-year optimization horizon some sort of simplification is required to obtain reasonable computational times. Moreover, the units are typically aggregated in this context. Therefore, a linear reformulation of the model seems appropriate. In this talk we compare different linear formulations of the unit commitment problem and discuss which formulation is best suited for our application. We present solutions for a large real-world electricity market model using these reformulations.

**3 - Cooperation of TSO and DSO to provide re-dispatch capacities**

*Michael Zipf, Dominik Möst*

Overview Today, ancillary services, such as congestion management, are mainly provided by large power plants which are located in the transmission grid. Due to the energy transition in Germany generation capacities will shift from the transmission to the distribution level. Thereby in the future the role of transmission and distribution system operators will change especially with regard to the provision of ancillary services. Thus the question is to which extent distribution system operators can actively contribute to system stability in the transmission system and how total system responsibility should be assumed by distribution system operators.

Methods A model based analysis is conducted to measure the impact of different cooperation regimes between the transmission and the distribution system operator (DSO). This problem leads to a Generalized Nash Equilibrium (GNE) and most likely no unique solution of the problem exists. A convenient approach for solving a GNE is presented and used in this analysis. Furthermore a detailed data set of the German electricity grid, including the transmission and distribution level, is used which forms a large scale optimization model. This paper gives first insights about economic implications of changing roles and examines the impact of a higher degree of coordination between distribution and transmission level to provide ancillary services.

Results Results indicate that a stronger cooperation of system operators yields positive effects for both players and substantial cost savings can be achieved. System responsibility of DSOs has to be extended in order to get access to all re-dispatch resources located in the distribution grid. This gets important with a high share of renewables in the electricity system.

with relatively low penalties (i.e., optimistic plans would be rather favorable) high power led participants to plan more optimistically and low power led participants to plan more pessimistically. The present research makes important contributions to both the behavioral operations literature and the management science literature by identifying a predictor of optimistic planning behavior and sensitivity to different cost types, respectively. It also yields interesting insights for the emerging stream of research on low-power individuals.

**2 - Delegated Testing of Design Alternatives: Selectionism vs. Trial-and-Error**

*Gerrit Schumacher*

During the development of a new product, firms are constantly confronted with challenging design choices. Typically, a variety of potential design alternatives exists and the firm aims to choose the one that promises the highest value. Upfront, however, the value of each alternative is unknown to the firm and therefore, it has to rely on design testing to gain (imperfect) information on a product's true value. In reality, these testing activities are carried out by project teams with interests not necessarily perfectly aligned with the firm's objectives. As a result, the firm has to design appropriate incentive schemes to motivate these teams to thoroughly test their designs and to truthfully reveal their acquired information. In this study, we derive the optimal incentive schemes for the two most wide-spread testing approaches - selectionism and trial-and-error learning - and compare their effectiveness.

**3 - Does Strategic Behavior Mitigate Parkinson's Law?**

*Sebastian Schiffels, Andreas Fügener*

Projects running late is a widely-known problem while the source of this problem, e.g. poor planning of the project managers, poor execution of the project workers, or a mixture of both, is often unknown. Buffer time might prevent that projects are running late at the cost of additional resource usage. However, buffers are even more costly if the planning and execution of a project is conducted by different actors (planner and worker) as Parkinson's Law comes into play. As a consequence a project almost never end before the time available for its completion. Determining the time available for a project the project planner is confronted with a challenging trade-off decision: insufficient time results in overtime or contractual penalties, too much time wastes limited resources like labor hours. In a setting with a project manager planning the time available and a project worker fulfilling the project the question arises how both influence each other, e.g. whether the time available to fulfill the project is influenced by Parkinson's Law. We develop a theoretical framework considering an interactive project setting with a planner and a worker demonstrating that the optimal decision of the worker is in line with Parkinson's Law in a single decision task. However, in many business situations planner and worker interact in several projects. Therefore, we also consider repeated interactions. Based on our theoretical framework we setup an experimental study and find support that work does not necessarily expand so as to fill the time available for its completion if planner and worker interact more than one time.

■ **TA-05**

*Thursday, 9:00-10:30 - Hörsaal 4*

**Behavioral Project Management (i)**

Stream: Game Theory and Experimental Economics

Chair: *Sebastian Schiffels*

**1 - The effect of power on cost planning in project management**

*Andreas Fügener, Sebastian Schiffels*

Managers routinely decide on deadlines, budgets, and quality levels, often facing a trade-off between increased costs by planning overly pessimistic, e.g. too much time, or paying penalty costs by planning overly optimistic, e.g. too little time. Current views from psychological research suggest that a managers' sense of power will bias this kind of decision, but it is unclear if it leads to greater pessimism or optimism in planning under uncertainty. We used an episodic recall task to manipulate the sense of power and a newsvendor paradigm with penalty costs in two online experiments with different penalty cost settings to test the predictions. The results indicate that in cost scenarios with relatively high penalties (i.e., pessimistic plans would be rather favorable) high power led participants to plan more pessimistically and low power led participants to plan more optimistically. In cost scenarios

■ **TA-06**

*Thursday, 9:00-10:30 - Hörsaal 5*

**Advanced Analytics in Revenue Management**

Stream: Pricing and Revenue Management

Chair: *Catherine Cleophas*

**1 - Nonparametric Demand Estimation in Revenue Management**

*Johannes Ferdinand Jörg, Catherine Cleophas*

Revenue management employs methods of demand forecasting and optimization to offer the right price at the right time to the right customer. Newer technology enables firms to store and access increasingly big data sets. This brings the challenge to incorporate the information contained in those data sets in revenue management. For example, current revenue management rarely exploits panel data. Our contribution proposes to estimate demand structures of a market from panel data using nonparametric methods. We employ finite mixtures to model booking events in different time frames and draw conclusions on the underlying structure. Synthetic data allows us to validate

the performance of the estimators in a controlled environment and then apply the procedure to a real data example from an international airline carrier. We discuss the results with respect to the underlying demand structure of the synthetic data set.

## 2 - Forecasting Price Elasticity with Generalized Additive Models assuming a Poisson Process with an Application to Dynamic Pricing

*Jan Felix Meyer, Goeran Kauermann, Catherine Cleophas*

Forecasting demand is a central question in airlines' revenue management. As the capacity of a flight is a perishable asset typically two different cost-types are evaluated. In order to achieve the objective of revenue maximization the airlines' control mechanism uses the cost-factors as input values to a control-scheme that defines the available price. This is done to guarantee that incoming bookings give a positive contribution to the objective. As sold seats cannot be offered again opportunity costs arise by the risk of spoilage if high yield customers are rejected due to overselling at discounted rates. Simultaneously the passengers' willingness-to-pay is estimated to control for price-elasticity-costs. These may occur if a seat is sold at a rate which is below the individuals willingness-to-pay. This paper will focus on the latter and discuss how statistical modeling is used to exploit the demand-price-relationship to control for price-elasticity-costs. In particular we will present how the shape constrained additive model framework is capable of discovering complex dependencies that impact price-elasticity. Subsequently it is shown how these estimates are utilized by a dynamic-pricing-scheme that sets the optimal-price equal to the marginal-revenue plus an additional cost factor. It is demonstrated by application of the proposed method to several real-data examples how this setup greatly simplifies the airlines' pricing. Further benchmarking the forecasting-performance for the purpose of dynamic-pricing the proposed model outperforms other techniques that recently appeared within the revenue-management literature.

## 3 - Exogenous Capacity Changes in Airline Revenue Management: Quantifying the Value of Information

*Catherine Cleophas, Daniel Kadatz, Natalia Kliewer*

Frequently, airlines cannot operate flights with the initially scheduled aircrafts as technical defects, crew planning, weather conditions, etc. cause unexpected changes. These aircraft changes can alter the number of salable seats - the aircraft's capacity - and thus affect revenue management results. Capacity changes that are intentionally driven by revenue managers to better match volatile demand have been addressed by existing research. However, current research and practice rarely consider unexpected exogenous changes, although these cause uncertainty of unquantified magnitude.

This presentation proposes an approach for systematically considering exogenous capacity changes in airline revenue management. Multiple solution methods are tested in a simulation environment calibrated on empirical data. We compare solutions with regard to revenue performance and the required information on the timing, magnitude, and probability of changes. Thus, we quantify the value of information when accounting for exogenous capacity changes in airline revenue management.

## ■ TA-07

*Thursday, 9:00-10:30 - Hörsaal 6*

### Behavioral Contracting (i)

Stream: Game Theory and Experimental Economics

Chair: *Karina Held*

#### 1 - Sticky Wages and Effort Inertia - Experimental Evidence on Productivity and Distribution Effects under Inflation

*Karina Held*

In a controlled laboratory experiment, we study the impact of inflation and deflation on work relationships with incomplete contracts. With inflation, we observe that effort is only partially adjusted to the decreasing real wages. This is in line with money illusion and results in a lower cost of labor, but it also leads to lower total earnings than in an economy with stable prices. With deflation, the cost of labor is greater than with stable prices, but total earnings are not. While overall productivity is greatest with stable prices, the employer's share of total earnings is highest with inflation and lowest with deflation.

#### 2 - Efficiency of two-part tariffs in supply chains: The role of bargaining power and demand uncertainty

*Abdolkarim Sadrieh, Guido Voigt*

Using laboratory experiments, we study behavior in supply chains with two-part tariffs and price-sensitive demand. We vary the degree of bargaining power between the supply chain partners by varying their outside options. In addition, we examine the role of demand uncertainty by comparing treatments with stochastic demand to treatments with deterministic demand. In theory, the efficiency of supply chains with two-part tariffs is independent of all of our treatment variations, but the distribution of payoffs is not. However, while the normative benchmark (with rational and expected profit-maximizing players) predicts an efficient outcome in all treatments, we observe substantially better supply chain performance when buyers have the high outside option (i.e. high bargaining power) but do not face demand uncertainty. Surprisingly, the effect is reversed when buyers face demand uncertainty. With demand uncertainty, supply chains perform better when buyers have low bargaining power. We discuss these results taking behavioral motives (e.g. loss aversion and fairness concerns) of buyers and suppliers into consideration.

#### 3 - The effect of communication media on forecast information sharing in supply chains

*Lennart Johnsen, Guido Voigt, Joachim Weimann*

We consider the pricing decision of a supplier delivering to its retailer. The retailer has an incentive to understate her private information about end-customer demand in order to negotiate a lower retail price. This harms the overall supply chain performance. Game theory predicts that communication cannot resolve this incentive conflict. We examine in laboratory experiments the impact of unilateral and bilateral communication forms on retailer's trustworthiness, supplier's trust and the supply chain performance.

## ■ TA-08

*Thursday, 9:00-10:30 - Seminarraum 101/103*

### Container and Terminal Operations I (i)

Stream: Logistics, Routing and Location Planning

Chair: *Julia Funke*

#### 1 - Berth Allocation - Do we have it all wrong?

*Stefan Voss*

The Berth Allocation Problem (BAP) aims at assigning and scheduling incoming vessels to berthing positions along the quay of a container terminal. This problem relates to well-known optimization problems within maritime shipping. During the last decades many terminal operators and many academics have developed algorithms and decision support systems for optimizing berth planning including the BAP at container terminals. Moreover, we have seen quite a few extensions of the problem settings to incorporate, e.g., integrated problems or time-dependent limitations (tidal changes) and many more. Despite a wealth of existing systems as well as various recent surveys from literature there are still quite a few realistic issues that seem to be neglected including the consideration of berth error as well as disturbances in the daily operation. That is, in this paper we set up a research agenda pointing out that we need to consider and model disturbances and stochastic influences to make the problem more realistic.

#### 2 - A Mixed Integer Programming Model for Integrated Operations in Container Terminals

*Damla Kizilay, Deniz Türsel Eliiyi*

In this study, operations in sea port container terminals, namely the quay crane assignment and scheduling, yard crane assignment and scheduling, yard location assignment and yard vehicle dispatching are examined simultaneously. The operations of quay cranes, yard trucks, and yard cranes should be well coordinated in order to decrease vessel turnover times, which is the principle target of container terminals. We concentrate on minimizing the vessel turnover time by integrating the optimization of all examined operations. While a majority of the existing studies consider individual operations thoroughly, only some integrate up to three or four problems, without taking into account some important restrictions of container terminals in practice. Realistic restrictions such as blocking constraints for the handling equipment, precedence constraints for the containers are respected in our study.

Loading and discharging containers of a vessel are considered simultaneously to reduce transportation times inside the terminal. We aim to propose an aggregate plan for all interrelated operations that need to be solved efficiently, in order to reflect the complete terminal system. The integrated problem is formulated as a mixed integer programming (MIP) model. As this holistic approach to quay and yard operations optimization brings complexity due to the integration of several connected problems, a heuristic approach is also developed for obtaining fast approximate solutions. Numerical experiments are conducted to evaluate the performance of the developed MIP model and the heuristic approach.

### 3 - Multi-size Container Transportation

*Julia Funke, Herbert Kopfer*

Within intermodal container transportation chains, the trucking sections cause between 25% - 40% of all costs incurred. We address a combined problem of assigning empty containers to transportation requests and routing trucks carrying containers. The problem definition assumes empty containers to be arbitrarily interchangeable with each other. This assumption leads to flexible transportation requests that do not have specified beforehand, which empty container is to be used to transport which cargo. Inbound containers can either be reused for outbound transportation requests (street-turns) or empty containers can be stored at and obtained from a common place, the depot. Each truck is able to transport up to two 20-foot containers or one 40-foot container. The objective is to minimize the total travel distance of a homogeneous fleet of trucks while fulfilling all requests within their time windows. We present an adaptive large neighborhood search that assigns containers using mathematical programming techniques and constructs routes of trucks using heuristics.

Chu and Beasley (1998), MIPLIB 2003 (Achterberg, Koch, and Martin, 2003), and MIPLIB 2010 (Puchinger et al., 2010). How good and powerful can be such a simple system?

### 3 - Benchmarking: Extending the range of H.D. Mittelmann

*Werner Helm, Jan-Erik Justkowiak*

As each and every software vendor tries to present its own products in a best possible way truly independent comparisons (benchmarks) are an invaluable source of information for any decision maker who decides upon a company's information technology. With regard to OR-Software and solvers for LP-, MILP-, Network- and related problems Hans D. Mittelmann of Arizona State University has almost attained Kult-status: several times a year he publishes benchmarks that define the state-of-the-art. There is no easy and direct way to assess or compare market shares (volume or dollars). Some company people speak of the 'big four' of commercial vendors comprising (could be disputed) IBM - ILOG-CPLEX, FICO - XPRESS, GUROBI - Gurobi Solvers and SAS Institute - SAS/OR. Up to most recently only the first three (plus MOSEK, Matlab and open source products) had been covered by H.D. Mittelmann. Hence we set out to extend this range to cover SAS/OR, too. As benchmarks depend on a large number of parameter settings starting from hardware, OS, etc. we directly compared SAS/OR with GUROBI and used our results on GUROBI to link these numbers to Mittelmann's suite of benchmarks. Derived from recent projects we added a class of problems called Tourenplanung (VRP). We present what appears to be the first independent benchmarking of SAS Institute's OR-solvers.

## ■ TA-09

*Thursday, 9:00-10:30 - Seminarraum 105*

### Modeling and Solver Performance

Stream: Software and Modelling Systems

Chair: *Werner Helm*

#### 1 - Planarization of CityGML models using a linear program

*Steffen Goebbels, Regina Pohle-Fröhlich, Jochen Rethmann*

CityGML is an XML based description standard for 3D city models that requires model buildings to have planar roof facets. Unfortunately, current tools that generate building models from airborne laser scanning point clouds violate this requirement to some extent. We propose a definition of approximate planarity and present a post-processing tool that establishes approximate planarity using linear optimization. It preserves the characteristic shape of roofs. In most cases, triangulation of non-planar facets is no longer needed. This not only reduces the number of facets and increases performance of applications that process city models, but also avoids disturbing lighting artifacts.

#### 2 - Distributed solving of mixed-integer programs with GLPK and Thrift

*Jochen Rethmann, Frank Gurski*

Branch-and-Bound algorithms for Mixed-Integer Programs (MIP) are studied for over 40 years, see for example Achterberg, Koch, and Martin (2005), Benichou et al. (1971), or Nygreen (1991). Object-oriented frameworks for parallel Branch-and-Bound algorithms like PICO (Eckstein, Phillips, Hart, 2001), MW (Goux, Linderoth, Yoder, 1999), ParaSCIP (Shinano, Achterberg, Berthold, Heinz, Koch, 2011), or ALPS (Xu et al., 2005) are well known. So why another paper about this topic? Our aim is to develop a powerful parallel MIP-solver by combining existing tools or frameworks that are platform independent and free of charge so that even small companies come to the benefit of an optimization suite. First of all, the solver should be easy to use without special skills in decomposition techniques, branching rules or programming. Licences of commercial solvers like CPLEX or GUROBI are often not affordable for small companies. Our tool combines the Gnu Linear Programming Kit (GLPK) and the remote procedure call framework Thrift. The GLPK-solvers are independently running processes to be independent of the further development of GLPK and algorithmic progress in future. We describe how to combine these two technologies to get an optimization suite for midsize problems and evaluate the power of our tool by solving some benchmark data from

## ■ TA-10

*Thursday, 9:00-10:30 - Seminarraum 108*

### Advances in Stochastic Optimization

Stream: Optimization under Uncertainty

Chair: *Marco Laumanns*

#### 1 - A maximum likelihood approach to optimization table balancing

*Geoffrey Brent*

Official statistical agencies often need to compile large tables of data from multiple sources. Errors in sources lead to inconsistent data, e.g. totals that should conceptually be identical do not match. To address this, tables must be "balanced" by adjusting entries to satisfy consistency constraints.

Some agencies approach this as an optimization problem, with a "level-preservation" weighted-least-squares (WLS) objective function that penalises adjustments. If variances for errors in individual sources are known, these can be used to set appropriate weights.

In practice, variances are often unknown. Weights may be set via models that estimate variance as a function of estimate magnitude, and type of source. Current implementations of this approach require setting model parameters subjectively, via expert judgement.

Level-preservation balancing can be interpreted as a maximum likelihood estimator (MLE) of the true data values, under a simple error model. I will show that this MLE interpretation offers a more objective method for setting model/weighting parameters.

Some balancing problems include time-series data where errors may be correlated over time. Previously this has been addressed by adding the level-preservation objective function to a "movement-preservation" objective based on Denton AFD/PFD metrics. This approach requires more subjectively-chosen parameters.

I show that although the movement- and level-preservation objectives are individually consistent with MLE estimates for simple error models, adding those two objectives together is not consistent with the corresponding MLE. By approaching balancing as a MLE problem we may be able to improve accuracy as well as reducing subjectivity of the optimization weighting.



## 2 - Scenario Aggregation using Binary Decision Diagrams for Stochastic Programs with Endogenous Uncertainty

Marco Laumanns, Utz-Uwe Haus, Carla Michini

Modeling decision-dependent scenario probabilities in stochastic programs is difficult and typically leads to large and highly non-linear MINLPs that are very difficult to solve. In this paper, we propose a new approach to obtain a compact representation of the recourse function using a set of binary decision diagrams (BDDs) that encode a nested cover of the scenario set. The resulting BDDs can then be used to efficiently characterize the decision-dependent scenario probabilities by a set of linear inequalities, which essentially factorizes the probability distribution and thus allows to reformulate the entire problem as a small mixed-integer linear program. The approach is applicable to a large class of stochastic programs with multivariate binary scenario sets, such as stochastic network design, network reliability, or stochastic network interdiction problems. Computational results show that the BDD-based scenario representation reduces the problem size, and hence the computation time, significantly compared to previous approaches.

## ■ TA-11

Thursday, 9:00-10:30 - Seminarraum 110

### Production Scheduling

Stream: Production and Operations Management

Chair: *Liliana Grigoriu*

#### 1 - Flexible production scheduling with volatile energy rates

*Christoph Johannes, Matthias Gerhard Wichmann, Thomas Spengler*

The expansion of renewable energies is a global phenomenon on the way to a sustainable power generation. The accompanying strongly fluctuating power supply is usually complemented by classical power plants in order to meet the current power demand. This results in a power market with dynamic electricity rates. In these markets, energy suppliers offer manufacturing companies two types of electricity tariffs. These are tariffs with fixed electricity rates and tariffs with variable electricity rates. For manufacturing companies tariffs with variable electricity rates provide an opportunity as in the course of energy-oriented production planning the schedule and the machine states can be planned and therefore the resulting energy costs are reduced. Moreover, the use of battery storage allows manufacturing companies to store comparatively cheap energy and to use this during periods of increased electricity rates for production. In order to exploit the resulting potentials, their consideration in companies' production planning is required. However, suitable approaches are missing so far. In the literature models for the flexible job-shop scheduling exist which take particular elements of an energy-oriented scheduling into account. But, a transfer of these elements on further planning tasks as the economic lot scheduling problem has not taken place. In this contribution we will present an extension of an economic lot scheduling problem for energy-oriented production with time-dependent purchase of energy. The aim of the model formulation is to minimize production-related costs based on forecasts of electricity rates. On the basis of an illustrative example, the operational cost reduction potential through battery storage and variable electricity rates is indicated.

#### 2 - Scheduling of uniform nonsimultaneous parallel machines

*Liliana Grigoriu, Donald Friesen*

We consider the problem of scheduling on uniform processors which may not start processing at the same time with the purpose of minimizing the maximum completion time. We give a variant of the MULTIFIT algorithm which generates schedules which end within 1.382 times the optimal maximum completion time for the general problem, and within (square root of 6)/2 times the optimal maximum completion time for problem instances with two processors. Both developments represent improvements over previous results. We also comment on how a PTAS for scheduling on a constant number of uniform processors with fixed jobs can be used to obtain a PTAS for scheduling on a constant number of uniform nonsimultaneous parallel machines, and present experimental results about the performance of our algorithm LMULTIFIT.

## 3 - Extension of the Quay Crane Scheduling Problem for scheduling of several rail-mounted robots and the development of a heuristic solver for fiber placement processes

Markus Schreiber, Rüdiger Ruwe

The automation of manufacturing large scale Carbon Fibre Reinforced Plastic (CFRP) components is still a relevant topic in research. It is necessary to speed up and improve production due to the increased demand for CFRP components. In the course of the project GroFi the German Aerospace Center (DLR) built a production plant for the fully automated manufacturing of large scale CFRP components for aerospace applications. It is located at the DLR Center for Lightweight-Production-Technology in Stade. One of the key features of the facility is the possibility of simultaneously producing CFRP components with multiple, mobile, rail-mounted robots. What is anticipated is that this concept will drastically increase the speed of the production process and, through the use of redundancies, reduce downtimes of the facility. In addition to the generation of numerical code for robots this introduces the need for scheduling their tasks. Scheduling on limited space with limited flexibility is prone to error when done manually. Therefore and according to the paradigm of current strategy Industry 4.0 an automated method is being developed. This presentation deals with the modelling of and a heuristic solution to this production process. In general both can be applied to processes of several robot units which are mobile on a single rail. The production process was formulated as a Mixed Integer Problem by using analogies to the Quay Crane Scheduling Problem. Furthermore, a genetic algorithm was developed and implemented as a heuristic solver.

## ■ TA-12

Thursday, 9:00-10:30 - Seminarraum 202

### Graphs and Networks

Stream: Metaheuristics

Chair: *Silvia Schwarze*

#### 1 - The Generalized Steiner Cable-Trench Problem with Application to Error Correction in Vascular Image Analysis

*Eric Landquist, Francis Vasko, Gregory Kresge, Adam Tal, Yifeng Jiang, Xenophon Papademetris*

The Cable-Trench Problem (CTP) is the problem of connecting buildings on a campus to a building housing the central server so that each building is connected directly to the server via a dedicated underground cable. This problem is modeled by a weighted graph in which the vertices represent buildings and the edges represent the only allowable routes for digging trenches and laying cables between two buildings. Edge weights typically represent distance. A Steiner version of the CTP considers the possibility in which some subset of the campus buildings is connected to the central server.

In this talk, we define the Generalized Steiner Cable-Trench Problem (GSCTP), which considers the situation in which, even for the same distance, the cost of digging a trench is more costly for some edges versus others because of soil composition or physical obstacles, for example. The GSCTP has several natural applications, but we will focus on its nontrivial and novel application to the problem of digitally connecting micro-CT scan data of a vascular network and eliminating false-positive results. The CTP and its variants are NP-hard, so determining exact solutions to very large instances of the GSCTP are computationally infeasible. However, we show that straightforward modifications to Prim's algorithm find very good approximations to exact solutions to the GSCTP efficiently. This solution strategy allows us to fully automate the error-correction process in our application to vascular image analysis.

#### 2 - Interactive Metaheuristics for Network Optimization Problems

*David Meignan*

Interactive optimization is the process of interacting with an optimization system in order to enrich an optimization problem or to obtain better optimization performances. Interactive optimization can be used for instance when an optimization model contains inaccuracies, such

as simplifications to make a problem tractable, and the user of the optimization system is able to identify them. In this case, the interaction should prevent unrealistic or unfeasible solutions to be adopted.

Interactive optimization approaches range from rudimentary trial-and-error approaches to more sophisticated approaches such as interactive multiobjective optimization, human-guided search or long-term preference inference. Most of the optimization procedures implemented for these interactive approaches are heuristics and metaheuristics. In fact, interactive optimization is often used when optimization models or problem data need to be enriched by the user. In this context, an optimal solution with respect to the problem model may not be worth the computational time because the solution may not be optimal from a user's perspective. Therefore, metaheuristics are particularly attractive for interactive optimization as they provide good solutions in reasonable time.

We recently proposed a classification to better understand the interaction mechanisms in interactive optimization. This classification considers four aspects of the interaction: the role of the user, the type of feedback integration (model-free or model-based), the lifetime of preference information (step-based, short or long-term), and the type of optimization procedure. In this presentation I detail this classification and illustrate it with interactive metaheuristics applied to network optimization problems.

## ■ TA-13

Thursday, 9:00-10:30 - Seminarraum 204

### Error Bounds and Algorithms

Stream: Control Theory and Continuous Optimization

Chair: *Andreas Fischer*

#### 1 - Convergence of Newton-Type Methods for Degenerate Complementarity Systems

*Andreas Fischer, Markus Herrich, Alexey Izmailov, Mikhail Solodov*

We consider complementarity systems with nonisolated solutions which, for example, may come from Karush-Kuhn-Tucker (KKT) systems of nonlinear programs or generalized Nash equilibrium problems. The complementarity systems are reformulated as systems of piecewise continuously differentiable equations. Then, the local convergence of appropriate Newton-type techniques applied to these nonsmooth systems is dealt with. It is shown that the only structural assumption needed for rapid local convergence of such methods is the piecewise error bound, i.e., a local error bound holding for the branches of the solution set resulting from partitions of the bi-active complementarity indices. The latter error bound is implied by various piecewise constraint qualifications, including relatively weak ones. We apply our results to KKT systems arising from generalized Nash equilibrium problems.

#### 2 - A Globally Convergent LP-Newton Method for Constrained Piecewise Differentiable Systems of Equations

*Markus Herrich, Andreas Fischer, Alexey Izmailov, Mikhail Solodov*

The LP-Newton method has been recently proposed for the solution of constrained systems of equations. It turned out that this method has very strong local convergence properties. In fact, it converges locally quadratically under assumptions implying neither differentiability nor the local uniqueness of solutions.

However, the question concerning a suitable globalization was not satisfactorily answered yet. In this talk an algorithm based on the LP-Newton method is presented which uses a linesearch technique for the natural merit function. The new algorithm keeps the strong local convergence properties but has, in addition, global convergence properties.

#### 3 - Projected Levenberg-Marquard methods under the constrained error bound condition

*Klaus Schönfeld, Roger Behling, Andreas Fischer, Gabriel Haeser, Alberto Ramos*

We consider a smooth system of nonlinear equations subject to a closed convex feasible set. The projected Levenberg-Marquard method projects the result of a classical Levenberg-Marquard step onto the feasible set. This method is known to be Q-superlinearly convergent to a (possibly nonisolated) solution of the constrained system of equations if an error bound condition holds locally both for feasible and infeasible points. It was proved recently that a combination of two weaker local error bound conditions guarantees at least R-linear convergence. In this contribution, we show that one of these conditions can be omitted without losing the linear convergence. What is still needed is the constrained error bound condition, i.e. a condition for feasible points only. The derivation of this result led to the interesting fact that under the constrained error bound condition the solution set of the constrained system can be locally represented as an intersection of a differentiable manifold with the feasible set.

## ■ TA-14

Thursday, 9:00-10:30 - Seminarraum 206

### Scalarizations, Bounds and Mathematical Programming Methods

Stream: Decision Theory and Multiple Criteria Decision Making

Chair: *Nikolai Krivulin*

#### 1 - Efficient Bound Computations in Multiobjective Optimization

*Kathrin Klamroth, Kerstin Daechert, Renaud Lacour, Daniel Vanderpooten*

Given some (partial) knowledge on the nondominated set of a multiobjective optimization problem, the search region corresponds to that part of the objective space that potentially contains additional nondominated points. We consider a representation of the search region by a set of tight local upper bounds (in the minimization case). While the search region can be easily determined in the bi-objective case, its computation in higher dimensions is considerably more difficult and gives rise to an interesting relation to computational geometry. We discuss the usefulness of local upper bounds in Branch and Bound type algorithms as well as in scalarization based solution methods, aiming at concise representations of the nondominated set.

#### 2 - Methods of tropical optimization in rating alternatives based on pairwise comparisons

*Nikolai Krivulin*

We consider unconstrained and constrained optimization problems in the framework of the tropical (idempotent) mathematics, which focuses on the theory and applications of semirings with idempotent addition. The problems are to minimize or maximize functions defined on vectors over idempotent semifields (semirings with multiplicative inverses). We examine several problems of rating alternatives from pairwise comparisons, including problems with constraints on the final scores of alternatives, and multi-criteria rating problems. We reduce the problems to the log-Chebyshev approximation of pairwise comparison matrices by reciprocal matrices of unit rank, and then represent the approximation problems as optimization problems in the tropical mathematics setting. To solve these problems, methods of tropical optimization are used to provide direct, complete solutions in a compact vector form. We discuss the applicability of the results to real-world problems, and provide numerical examples.

## ■ TA-15

Thursday, 9:00-10:30 - Seminarraum 305

### Flows and Queues

Stream: Project Management and Scheduling

Chair: *Martin Josef Geiger*

## 1 - Linking Queueing Theory and Scheduling Approaches

*Kathrin Benkel, Rainer Leisten*

Stochastic queueing theory on the one hand and static-deterministic scheduling on the other hand are both widely used approaches in their respective literature, but in most cases discussed separated from each other. Referring to queueing approaches it is known that each type of variability, and especially its increase, reduces the performance of manufacturing systems and has to be buffered by an efficient mix of time, inventory and/or capacity (Hopp/Spearman, 2008, Factory Physics). Variability can be divided into operations variability (variability in processing times) and flow variability which defines the way jobs arrive and leave a production system (arrival and departure variability) (Hopp/Spearman, 2008, Factory Physics). In static-deterministic scheduling, variability is often discussed as part of an objective function, e.g. minimization of completion time variance (CTV) or minimization of variability of completion time differences (CTDVB2). While the CTV problem tends to finish all jobs at the same time (which is impossible), CTDVB2 is aimed at smoothing the distance in completion times of two consecutively scheduled jobs. This can be interpreted as departure variability of jobs in queueing approaches and as a first link between queueing theory and scheduling (Leisten, Rajendran, 2015, Variability of completion time differences in permutation flow shop scheduling). In this presentation, we continue with connecting both approaches by discussing arrival variability and operations variability in deterministic permutation flow shop systems.

## 2 - Analysis of integrated scheduling and intermediate transportation systems in production lines with variability-related measures

*Miriam Zacharias, Rainer Leisten, Rajendran C*

In 2015, Leisten and Rajendran introduced the variability-related objective function CTDVB2 which aims at smoothness of a flowshop's output by minimizing the difference of completion times of two consecutively scheduled jobs. In this presentationwork, CTDVB2 and modifications of CTDVB2 are investigated in a serial assembly system. The influence of variability in one system on the overall performance of the combined system is evaluated via computational experiments. First, a single flow shop with transport unit is evaluated from a scheduling perspective. The makespan and flowtime values of the NEH-solution are taken as benchmarks for the performance of the new objective function from a scheduling perspective. Then, two flow shops in series with and without inter-shop logistics are analysed from a queueing perspective, while keeping track of the classical scheduling performance measures. While system 1 is defined as a standard permutation flowshop, system 2 is not looked at into detail but interpreted in terms of queueing indicators (e.g. its utilization). The interdependencies of the two approaches are analyzed by tracking the total flowtime of the joined system, which is estimated by the sum of processing times of system 1 and 2 and the waiting time of jobs in the queue between the two flowshops (approximated by the Kingman -equation). Looking at the overall performance from scheduling and queueing perspectives shall help to close the gap between static-deterministic scheduling and dynamic-stochastic queueing theory.

## 3 - Optimal Torpedo Scheduling in Steel Production

*Martin Josef Geiger*

The talk presents a solution approach for the torpedo scheduling problem, a planning problem arising in steel production. In this application, torpedoes carrying liquid iron must be routed through a system of production stages within a steel mill. This implies the detailed scheduling of the torpedoes, as the production stages, such as desulfurization stations, buffer zones, oxygen converters, are of limited capacity and thus may only hold a finite number of torpedoes at each time step. We currently employ a Branch-and-Bound (BnB) algorithm for the problem at hand. Due to the complexity of the problem, and due to the size of the available problem instances, the search for optimal solutions sometimes must be restricted to a reasonable running time, resulting in a time-truncated BnB. Good heuristics for guiding the search process must therefore be integrated into the solution approach. We have developed some ideas for this. The solution algorithm is tested on benchmark instances from the literature. We currently are, together with two other teams, ranked first in the ongoing ACP Challenge on the Torpedo Scheduling Problem, and implementation challenge of the 22nd International Conference on Principles and Practice of Constraint Programming.

## ■ TA-16

*Thursday, 9:00-10:30 - Seminarraum 308*

## Planning health care services

*Stream: Health Care Management*

*Chair: Jens Brunner*

### 1 - Improving health care service in rural areas by mobile medical units

*Christina Büsing, Martin Comis*

Already today there is a shortage of up to 1,000 general practitioners (GPs) in rural areas. Planning a sustainable supply in the future is even more important, since the number of elderly people in these areas will increase as younger people tend to move to urban areas. To ensure and to improve ambulatory care in rural areas, the Statutory health insurance pursues the setup of mobile medical units.

Based on a fixed number of mobile medical units, this problem can be modeled as a  $k$ -median problem. However, it is counterproductive to treat mobile units as normal practice with limited office hours. The modeling includes therefore the ability to adapt to the daily changing demand of medical treatments at different locations. However, this flexibility should not lead to changing locations on a daily or hourly base. Stability of the office hours and locations are important for the medical staff as well as for the public acceptance. This trade-off between adaption to the actual demand and stability can be well modeled with a recoverable robust extension of the classical  $k$ -median problem.

In order to evaluate the effects of using mobile medical units we implemented an agent based simulation to evaluate the coverage of medical treatment, the expected idle time, the average waiting time for an appointment or the expected changes of locations and offices hours. Next to our models, we will present the simulation and first results on the effects of using mobile medical units.

### 2 - Locating and designing group practices for general practitioners

*Melanie Reuter-Oppermann, Jost Steinhäuser*

In Germany the future lack of general practitioners (GP) will be a major challenge for the healthcare system. In Baden-Württemberg around 24% of all GPs will retire in the next eight years. These almost 2000 GPs are looking for a successor for their practices as well as for their patients. Underlining the current situation, in the next eight years at least 500 practices will probably be closed as there are too little successors, leaving 750.000 patients with the need to find a new GP. Main reasons are that many newly qualified GPs are more interested in an employment or sharing a practice than having their own. Especially female doctors demand possibilities for part-time employments. With 70% of all GPs being female doctors they build the majority of future GPs. Due to the demographic change rather more than less GPs will be needed in the future to provide close to home primary medical care for the German population. One idea to overcome this challenge is to build new group practices for 4 (or more) GPs that allow for (part-time) employments. In this work we present planning problems when building new group practices and discuss corresponding formulations and solution approaches. Arising questions include: (1) how many practices with how many GPs are needed, (2) where should the practices be located, (3) how should the practice be designed, (4) how many medical assistants are needed and (5) how can their shifts be scheduled? Exemplary results of a location study for the administrative district of Rottweil that took current locations, possible closings and future demand into account will be presented. Additionally, layouts for new GP practices with two examination rooms per doctor based on a study for a large group praxis in Baiersbronn, Germany, will be discussed.

### 3 - Analyzing economies of scale and scope in hospitals using non-linear optimization

*Sebastian Hof, Jens Brunner*

The case mix planning problem deals with choosing the ideal composition and volume of patients in a hospital. Major changes in hospital size, e.g., due to mergers or acquisitions, can lead to significant changes in operational efficiencies. We formulate a generic non-linear mixed integer program using non-linear production functions to model such operational efficiencies in case mix planning. Since the problem cannot be solved with standard solution methods for realistic problem instances, we develop an iterative linear approximation scheme that provides lower and upper bounds converging against the optimal value of the objective function. The model is applied to real data from German hospitals. We find that the consideration of non-linear production

functions adds significant value to case mix planning models if major changes in scale are planned as opposed to scenario analyses with minor adaptations of production scale.

## ■ TA-18

Thursday, 9:00-10:30 - Seminarraum 401/402

### Collaboration In Logistics

Stream: Logistics, Routing and Location Planning

Chair: *Margaretha Gansterer*

#### 1 - Transportation Planning in a Sharing Economy Setting

*Moritz Behrend, Frank Meisel*

The rise of the sharing economy fosters a shift from a purchase-based towards an access-based consumption. After all, the need of purchasing items that are used on rare or just temporal occasions dwindles when, as a member of a sharing community, one can access them need-based. Examples for such items are tools, children's clothing, or leisure equipment. The matching of supplies and demands of such items within a community can be coordinated via online platforms. The actual forwarding poses a transportation challenge, as the peer-to-peer exchange needs to address the highly inefficient "last mile" twice. We model the resulting logistics-planning problem on a network of given supplies, demands, and planned trips of the community members. Mathematical optimization models are developed to assign supplies to demands in a first step and, in a second step, to modify the given trips so as to pickup and drop-off the items at acceptable effort for the travelling community members. The optimization models resemble assignment problems and vehicle routing problems. In this talk, we discuss the problem setting and the developed models in detail. We analyze to which extent these problems can be solved using standard MIP-solvers like Gurobi and what logistical benefit a sharing community can gain from such an approach. For this purpose, we propose a first set of benchmark instances together with detailed computation results.

#### 2 - The Political Campaigning Problem: A Selective and Periodic TSP Perspective on Electoral Campaigns

*Deniz Aksent, Masoud Shahmanzari*

The Political Campaigning Problem (PCP) deals with determining daily routes for a party leader who holds meetings in various cities during a campaign period of 30 days. On a graph with static edge costs and time-dependent vertex profits, PCP seeks a closed or open tour for each day. The objective is the maximization of the net benefit defined as the sum of reward points collected from meetings in the visited cities minus the traveling costs normalized into a compatible unit. The leader is not required to visit all cities making the problem selective. Moreover, he can stay overnight in any city. This means there is no fixed departure node (no depot). We consider the provinces of Turkey in addition to the capital city Ankara which serves as the center of the campaign. Each city is associated with a specific base reward and a visit duration. The leader can travel from one city to another city either by bus or by flying through three hub cities. He can stay overnight in a city other than the capital Ankara. However, he cannot be outside Ankara for more than four days in a row. The total length of the talks and travel times between cities on the same day cannot exceed 14 hours. The proposed model utilizes a multifaceted reward function. It calculates the reward point of each city considering four factors: i) Population, ii) The vote rate in the previous election and the criticality of the votes, iii) The number of remaining days until the election, iv) The number of days passed since the previous meeting in that city. As we get closer to the election day, the reward points of crowded cities increase significantly. On the other hand, successive meetings in a city are severely depreciated. We propose a MILP formulation in which we capture many real-world aspects of the PCP.

#### 3 - Solving the centralized problem for a two-clustered transport collaboration network

*Adria Soriano, Margaretha Gansterer, Richard Hartl*

We are dealing with centralized solutions in a complex collaborative transportation network, where shipment services are interchanged within a network of carriers. Shipments are considered to be performed between two far away regions. We consider shipments of goods in a

three-stage setting. Goods are collected via local trips and consolidated in a hub in one region, transported via long-haul to a hub in the other region, and delivered by local trips again. Local trips depart and arrive to a hub and can visit collection and delivery points in the same tour. Each carrier is assumed to have at least one hub in each region. This problem setting represents on the one hand, a realistic scenario of the transportation industry. On the other hand, it involves less-than-truckload tours, which so far have only rarely been considered in the context of carrier collaboration. For solving the centralized planning problem we split it into two parts: (i) the assignment of customers to depots and (ii) the routing. Capacity and time restrictions are taken into account. We present results for different classes of test instances.

## ■ TA-19

Thursday, 9:00-10:30 - Seminarraum 403

### Integrated Public Transportation Planning (i)

Stream: Traffic and Passenger Transportation

Chair: *Marie Schmidt*

#### 1 - Integrated Traffic Planning in Grid Graphs

*Alexander Schiewe, Philine Gattermann, Anita Schöbel*

Integrating the different steps in transportation planning (in our case line planning, timetabling and vehicle scheduling) is a problem considered in ongoing research. Until now, these problems are solved sequentially in fixed order. The main disadvantage of this procedure is that once the line plan is fixed, it cannot be changed anymore, therefore reducing the number of possible timetables and vehicle schedules and possibly impairing the quality of the overall solution drastically.

In this talk we examine integrated traffic planning in grid graphs.

Since the integrated problem stays NP-hard on grid graphs, we use a so-called Eigenmodel approach, optimizing the line plan, the timetable, and the vehicle schedule iteratively, always keeping two of the three variable sets fixed. We identify the resulting optimization problems, namely (1) finding a line plan when timetable and vehicle schedule are fixed, (2) finding a timetable when vehicle schedule and line plan are fixed, and (3) finding a vehicle schedule when line plan and timetable are fixed and give formulations for these. We analyze if these can be simplified in grid graphs. The different optimization problems are then solved sequentially in different orders to improve the quality of a given solution for the integrated problem.

We will apply this algorithm to grid graphs of increasing size and discuss the performance in computation time and quality of the obtained solutions as well as convergence observations.

#### 2 - A SAT-Formulation for Integrating Line Planning, Timetabling and Passenger Routing

*Philine Gattermann, Peter Großmann, Karl Nachtigall, Anita Schöbel*

In public transportation planning, line planning and (periodic) timetabling are well researched problems. They are mostly solved sequentially. However, the sequential approach potentially inhibits optimal solutions to the integrated problem, as a fixed line plan greatly restricts the number of feasible timetables. Thus, we are aiming to find a solution for both problems simultaneously. To this end, we propose an integrated model for line planning and timetabling, where the passengers are routed during the optimization process on shortest paths according to their respective travel time. As line planning and periodic timetabling are both NP-hard problems and especially timetabling is computationally difficult, the integrated problem will be even harder to handle. Therefore, we decided to extend the currently best performing formulation for periodic timetabling, which is a SAT-formulation proposed by Großmann et al. (2012). While feasibility of the integrated problem can be modeled by a satisfiability problem, we need an extension of SAT to model the objective function. We chose a partial weighted maxSAT problem, which allows to handle constraints which have to be fulfilled and to minimize the travel time as objective function. Furthermore, we compare this partial weighted maxSAT-formulation to an IP-formulation of the integrated line planning, timetabling and passenger routing problem and discuss the advantages and disadvantages of each formulation.

**3 - Line planning with user-optimal route choice***Marie Schmidt, Marc Goerigk*

We consider the problem of designing lines in a public transport system, where we include user-optimal route choice. The model we develop ensures that there is enough capacity present for every passenger to travel on a shortest route. We present different integer programming formulations for this problem, and discuss exact solution approaches as well as a genetic solution algorithms.

**■ TA-20***Thursday, 9:00-10:30 - Seminarraum 404***Forecasting with Artificial Neural Networks**

Stream: Business Analytics and Forecasting

Chair: *Sven F. Crone***1 - Forecasting Model Selection for Industry Data by Applying Meta-Learning with Feature Selection***Mirko Kück, Sven F. Crone, Michael Freitag*

Demand planning is an important task for manufacturing companies since it is the main basis for all following steps of production planning. Typically, the future demand per stock-keeping-unit has to be forecasted based on time series of past customer orders. With several statistical methods created for different time series patterns, large scale applications on 10,000s of times series require a method selection, often done manually by human experts based on time series characteristics, or automatically using error metrics of past performance. However, the task of selecting adequate forecasting models can also be viewed as a supervised learning problem. For instance, a neural network can be trained as a meta-learner relating characteristic time series features to the ex post accuracy of forecasting models for each time series. Past research has proposed different sets of time series features for meta-learning, including simple statistical or information-theoretic as well as model-based features, and landmarks. This paper performs a feature selection on the different predefined sets of meta-features to provide a basis for a neural network meta-learner selecting between four statistical forecasting models. A large-scale empirical study on NN3 industry data shows promising results of the meta-learning approach for selecting appropriate forecasting models. The best model selection performance was achieved by the meta-learning approach with feature selection, leading to higher forecasting accuracy than approaches using the predefined feature sets as well as different benchmark methods for model selection, including the selection of the forecasting model with lowest error on the training set or the validation set, which is widely applied as best practice in industry.

**2 - The Value of Visualization in Forecasting Applications***Dennis Eilers, Daniel Olivotti, Michael H. Breitner*

The price of commodities is a critical success factor for a variety of companies. To identify the best possible time for a purchase in the future decision support systems based on forecasting models are used. Artificial Neuronal Networks (ANN) are a sophisticated method for non-linear time series forecasts. ANNs are trained with historical data to forecast future price paths. In most cases network ensembles are used. These ensembles consist of several thousand single networks. Due to random initialisation each network creates a different path. To visualize the information, several aggregation techniques can be applied. When using the simple arithmetic mean or the median the information of the ensemble gets pooled in a single path. For a decision maker this kind of presentation is easy to interpret. However, this may lead to misinterpretations if several bundles of paths with different implications emerge. With a heatmap visualization the information content can be significantly increased, as divergent assessments within the ensemble can be made visible. Our aim is to quantify the benefits of different types of visualizations. For this purpose, a design for a laboratory experiment is presented, in which the quality of the decisions of people based on various visualization techniques is examined. This results in recommendations for the implementation of visualizations in practical applications.

**3 - Neural network initialisation for time series prediction - an empirical evaluation of different methodologies on Industry Data***Sven F. Crone*

Artificial neural networks require multiple initialisations of their starting weights for training, and a number of methodologies have been proposed to set initial starting weights. In addition to the standard procedure, using starting values drawn at random from a uniform distribution around zero, e.g. [-1; 1], [-0.5; 0.5] Sarle (2002), a number of alternative initialisation methodologies have been proposed by Nguyen and Widrow (1990), Drago and Ridella (1992), Wessels and Barnard (1992), Yam and Chow (2000) and LeCun et al. (1998), which promise enhanced accuracy, efficiency or robustness. Although their merit has recently received increasing attention for architectures of deep neural networks used in image recognition, no attention to these methodologies has been given in their application for multilayer perceptron in time series prediction and forecasting. This paper seeks to remedy this omission and assess the effect of different initialisation techniques in an empirical evaluation on real-world industry time series, using a representative experimental design of fixed-horizon forecasts across multiple rolling time-origins, and using robust error metrics. The results suggest that the selection of an adequate initialisation methodology has a significant impact on forecast accuracy, robustness and efficiency, which is larger than that of other meta-parameters in neural network modelling.

**■ TA-21***Thursday, 9:00-10:30 - Seminarraum 405/406***Airspace Networks**

Stream: Logistics, Routing and Location Planning

Chair: *Adam Schienle***1 - A VRP Based Mathematical Model for Airspace Sectorization***Aydin Sipahioglu, Şaban Temizkan*

Airspace is getting crowded day by day and to manage air traffic becomes much harder due to the fact that different types of aircrafts take place in the sky with having different purposes. Airspace sectorization or airspace sector design means partitioning of airspace so as to balancing workloads among the segments. In other words, it is determination of responsibility area for each controller team. Airspace sectorization is a special field of air traffic management problem and to obtain manageable sectors is important. All aircrafts in a sector are controlled by a team of controllers and it is demanded the variance of workload among sectors should be minimized. Airspace sectorization problem is also dynamic. Since conditions such as weather, national security and business connections are dynamic for a country, workloads are changeable. So, boundaries of sectors should be changed considering workloads. Because of this dynamic structure, an efficient sectorization method is required.

In this study, a vehicle routing problem (VRP) based mathematical model is proposed to obtain airspace sectors with balanced workloads. The model depends on discretization of the air space into quadrangles through geographical reference system. In order to calculate workload of each quadrangle, an Analytical Hierarchy Process (AHP) based method is also proposed. Airspace is described as a symmetric graph and it is shown on test problem that the model gives manageable and well balanced sectors.

**2 - Preprocessing Techniques for the Shortest Path Problem on Airway Networks***Adam Schienle, Marco Blanco, Ralf Borndörfer, Nam Dung Hoang, Thomas Schlechte*

We study a simplified version of the Flight Trajectory Optimisation Problem, which is the problem of finding a minimum travel time path between two airports on an airway network, a directed graph. We regard both wind speed and direction as functions of time, which allows us to model the problem as a time dependent shortest path problem with the FIFO property. While this problem has been extensively studied for road networks, airway networks have an essentially different structure: the average degree is higher, and shortest paths usually have only few arcs. We consider two well-known routing algorithms,

Contraction Hierarchies (CHs) and A\*. For the latter, we introduce a problem-specific potential function which is based on overestimating the optimal wind conditions. Our computational results on real world instances show that CHs do not perform as well as on road networks. On the other hand, A\* yields a speed up comparable to that of CHs, while at the same time maintaining much lower preprocessing times.

## Thursday, 11:00-12:30

### ■ TB-02

Thursday, 11:00-12:30 - Hörsaal 1

### Combinatorial Optimization (i)

Stream: Discrete and Integer Optimization

Chair: *Dennis Michaels*

#### 1 - Robust Assignments with Vulnerable Nodes

*Viktor Bindewald, David Adjashvili, Dennis Michaels*

Various real-life planning problems require making upfront decisions before all parameters of the problem have been disclosed. An important special case of such problem arises in scheduling and staff rostering problems, where a set of tasks needs to be assigned to the available set of personnel or machines (resources), in a way that all tasks have assigned resources, and no two tasks share the same resource. In its nominal form, the resulting computational problem becomes the assignment problem.

This talk deals with the Robust Assignment Problem (RAP) which models situations in which certain resources are vulnerable and may become unavailable after the solution has been chosen. Such unavailability can be caused e.g. by an employee's sickness, or machine failure.

The goal is to choose a minimum-cost collection of resources (nodes in the corresponding bipartite graph) so that if any vulnerable node becomes unavailable, the remaining part of the solution still contains sufficient nodes to perform all tasks.

We develop algorithms and hardness results for RAP and establish several connections to well-known concepts from matching theory.

#### 2 - On the stable set polytope of claw-free graphs: the class of icosahedral graphs

*Claudio Gentile, Anna Galluccio*

The problem of finding a complete linear description of the stable set polytope of claw-free graphs has been one of the major topics in combinatorial optimization since early Seventies. Indeed this problem was defined as a natural generalization of the Edmonds' result on the matching polytope. Even if there has been many advances in the last 15 years, the stable set polytope of claw-free graphs is still not completely described.

While it is known that this linear description contains facet defining inequalities with arbitrary many and arbitrarily high coefficients, the set of claw-free graphs whose stable set polytope is described only by inequalities with 0,1,2-valued coefficients is considerably large. In fact, in 2014 Galluccio, Gentile and Ventura proved that this set contains almost all claw-free graphs with stability number greater than three plus some of the building blocks with stability number smaller than or equal to three, identified by Chudnovsky and Seymour in 2008.

In this talk we show that another important class of claw-free graphs with stability number three is described by 0,1,2-valued coefficients inequalities: the class of icosahedral graphs.

#### 3 - Solution methods for the Quadratic TSP and its variations

*Rostislav Staněk, Oswin Aichholzer, Anja Fischer, Frank Fischer, J. Fabian Meier, Ulrich Pferschy, Alexander Pilz*

The traveling salesman problem (TSP) asks for a shortest tour through all vertices of a graph with respect to the weights of the edges. The symmetric quadratic traveling salesman problem (SQTSP) associates a weight with every three vertices traversed in succession. If these weights correspond to the turning angles of the tour, we speak of the angular-metric traveling salesman problem (Angle TSP). First, we consider the SQTSP from a computational point of view. In particular, we apply a rather basic algorithmic idea and perform the separation of the classical subtour elimination constraints on integral solutions only. It turns out that this approach is faster than the standard fractional separation procedure known from the literature. We also test the combination with strengthened subtour elimination constraints introduced by Fischer and Helmberg in 2013. Secondly, we provide a different, mathematically interesting MILP linearization for the Angle TSP that needs only a linear number of additional variables while the standard linearization requires a cubic one. Finally, we introduce MaxSQTSP, the maximization version of the quadratic traveling salesman problem.

Here it turns out that using some of the stronger subtour elimination constraints helps. For the special case of the MaxAngle TSP we can observe an interesting geometric property if the number of vertices is odd. We show that the sum of inner turning angles in an optimal solution always equals  $\pi$ . This implies that the problem can be solved by the standard ILP model without producing any integral subtours. Moreover, we give a simple constructive polynomial time algorithm to find such an optimal solution. If the number of vertices is even the optimal value lies between 0 and  $2\pi$  and these two bounds are tight.

## ■ TB-03

Thursday, 11:00-12:30 - Hörsaal 2

### Flexibility options in power markets

Stream: Energy and Environment

Chair: *Reinhard Madlener*

#### 1 - Towards quantifying customer needs from micro blog data in e-mobility

*Marc Goutier, Niklas Kuehl*

The identification and quantification of customer needs is an important process in order to design new products and services. As shown in previous work, it is possible to classify micro blog data (e.g. tweets) on their feature of containing a customer need or not by applying Machine Learning models. With such a model as a basis, we show that customer needs can be clustered and quantified in the relevant data for a domain of interest—in this case e-mobility—as long as the possibly occurring categories of needs are known in advance. To apply the proposed method to e-mobility, major needs in this field are identified from recent literature, resulting in four major categories: Cost-related, car-related, charging-related and social-related needs. Four disjunctive white lists containing keywords, generated from the previous literature review, serve as a foundation for the need quantification. A first study shows that a white-list-based automatic clustering—relying on occurrences of the keywords—already achieves a high precision in the categories cost (82.8%) and charging (95%). The recall is unsteady between poor 13.1% (car-related needs) and solid 70.5% (charging-related needs). Further results are discussed and interpreted.

In summary, the contribution of the paper is threefold: 1) It gives a state of the art overview of relevant literature for customer needs in the field of electric mobility. 2) It proposes, executes and evaluates an approach on how to quantify (previously known) needs from micro blog data. 3) It gives insights about the quantity of customer needs in electric mobility, being expressed on Twitter of a time span of six months in Germany.

#### 2 - Flexibility Options for Lignite-fired Power Plants - A Real Option Approach

*Barbara Glensk, Reinhard Madlener*

The energy system transformation process "Energiewende" in Germany means, on the one hand, the promotion of (to a significant part intermittent) renewable energy technologies and, on the other hand, increasing difficulties in the profitable operation of many modern conventional power plants due to decreasing wholesale power prices (due to the so-called "merit order" effect). Nevertheless, the conventional power generation technologies are still needed for security of supply reasons when there is little wind or sunshine, and to keep power generation and demand for electricity in balance. In light of these aspects and the specific situation of the German federal state of North Rhine-Westphalia the more specific problem of a further profitable operation of the lignite-fired power plants arises. In our study, we wanted to answer the following research questions: Should the lignite-fired power plants be operated till the end of their lifetime without any flexibility-enhancing technical modifications? What are the implications of operating the already existing lignite-fired power plants more flexibly? Which flexibility options ought to be taken into consideration? What is the optimal investment time for the flexibility options investigated? Are the investments in other power generation technologies more suitable to ensure the system stability instead of retrofitting lignite-fired power plants? In order to shed some light on these research questions we propose an optimization model that is based on real options analysis (ROA) or, more precisely, on the option to choose. In the proposed model, both economic and technical aspects of power plant operation are explicitly taken into consideration for investigating their profitability under enhanced flexibility.

### 3 - Using Optimization Models for a Technology-Neutral Coordination of Flexibility Options on the Power Market

*Lars-Peter Lauven, Jutta Geldermann*

The increasing supply of volatile renewable electricity leads to an increased need for flexibility in the power market. In addition to using electricity storage facilities such as pump storages, numerous flexibility options have been identified on both the supply and demand side of the power market. On the supply side, certain generators can interrupt and resume their operation in relatively short time frames. On the demand side, the increasing numbers of electricity consumers that engage in Demand Response schemes mean that an imbalance of the power market can, to some extent, also be met by adjusting consumer demand. The determination of the most favorable options in specific situations becomes more complex with the number of available options. In addition to the direct costs of using a flexibility option, technical constraints such as minimal or maximal times of operation, lead times and capacity need to be considered. In the context of virtual power plants, which coordinate a variety of flexibility options, increasingly complex decision problems therefore need to be solved. In this work, a combination of binary optimization models is presented that help to determine a technology-neutral operational ranking for a portfolio of flexibility options.

## ■ TB-04

Thursday, 11:00-12:30 - Hörsaal 3

### Demand Response and decentralized systems

Stream: Energy and Environment

Chair: *Hannes Hobbie*

#### 1 - Demand Response in Industrial Sites - Energy cost reduction using mathematical optimization

*Sleman Saliba, Lennart Merkert, Reinhard Bauer*

In this talk, we analyze the potential of energy cost reductions using mathematical optimization for demand response in industrial sites. The same models and concepts are applicable to commercial sites or residential areas. We speak of demand response when energy consumer dynamically increase or decrease their power consumption depending on the price or availability of energy.

In the power industry, we see an increase in business models where industrial sites profit from providing the flexibility of industrial processes to the power market using demand response. Industrial sites normally have own power generation units or regulated connections to the power grid or both. Moreover, they have critical industrial processes that consume energy as well as other non-critical processes and energy consumers. In additions, storage capabilities are often available.

We show how to combine production planning, energy management and energy trading in order to reduce the energy cost and increase the financial benefit from providing the flexibility to the grid operator. All this, without changing the production goals or moving production deadlines.

Finally we present successful real-world demand response applications, where industrial site operators could increase the productivity and the financial benefits using mathematical optimization for demand response. Demand Response is an essential component to benefit from the changing energy markets and to contribute to a sustainable power generation in the 21st century.

#### 2 - Simulation and Evaluation of the Market Potential of Virtually Connected Photovoltaic-Battery Systems with Respect to Decentralized Prosumers

*Hendrik Broering, Reinhard Madlener*

The widespread deployment of rooftop photovoltaic systems has been a striking implication of the German energy transition. The self-generation of households turns them from passive consumers of electricity into active "prosumers" (consumer-producers). In 2012, the so-called "grid parity" was reached in Germany, meaning that self-generated electricity has become cheaper than that purchased from the grid or, in other words, PV remuneration has become lower than electricity purchase cost. Consequently, it is economical to maximize the self-consumption of PV electricity. Following this opening wedge

between purchase cost and remuneration, the number of battery systems in private households in Germany has risen sharply in the recent past. The focus of our research is the analysis of the economic merit of a virtual aggregation of spare capacities (unused storage capacities) from those batteries. We refer to the resulting capacity as cloud capacity. To this end we develop a MATLAB model that simulates battery state-of-charge values resulting from PV generation and load profiles for individual prosumers. We then define a geographically separated decision-maker (independent prosumer, without a battery system), who demands the spare battery-capacities of those households in order to maximize the self-consumption quota. We simulate an entire year and determine sensitivities with regard to electricity transport costs, feed-in tariffs, operation strategies and electricity prices. Moreover, we evaluate the economic merit depending on the number and degree of decentralization of the prosumers. Based on our simulation results, we point out under which regulatory and technological conditions such a cloud model could indeed be profitable for the decision-maker.

## ■ TB-05

Thursday, 11:00-12:30 - Hörsaal 4

### Mechanism and Markets for IT Service Compositions

Stream: Game Theory and Experimental Economics

Chair: *Alexander Skopalik*

#### 1 - Economic Aspects of Service Composition: Price Negotiations and Quality Investments

*Simon Hoof, Sonja Brangewitz*

We analyse the economic interaction on the market for composed services. Typically intermediaries as providers of composed services interact on the sales side with users and on the procurement side with providers of single services. Thus, in how far a user request can be met often crucially depends on the prices and qualities of the different single services used in the composition. We study an intermediary who purchases two complementary single services and combines them. The prices paid to the service providers are determined by simultaneous multilateral Nash bargaining between the intermediary and the respective service provider. By using a function with constant elasticity of substitution (CES) to determine the quality of the composed service, we allow for complementary as well as substitutable degrees of the providers' service qualities. We investigate the evolution of these service qualities and the corresponding service providers' investments within a differential game framework.

#### 2 - Truthful Outcomes from Non-Truthful Position Auctions

*Paul Dütting, Felix Fischer, David C. Parkes*

Adding to a long list of properties that explain why the VCG mechanism is rarely used in practice, we exhibit a relative lack of robustness to inaccuracies in the choice of its parameters. For a standard position auction environment in which the auctioneer may not know the precise relative values of the positions, we show that under both complete and incomplete information a non-truthful mechanism supports the truthful outcome of the VCG mechanism for a wider range of these values than the VCG mechanism itself. The result for complete information concerns the generalized second-price mechanism and lends additional support to Google's use of this mechanism for ad placement. Particularly interesting from a technical perspective is the case of incomplete information, where a surprising combinatorial equivalence helps us to avoid confrontation with an unwieldy differential equation.

#### 3 - Strategic Formation of Customer Relationship Networks

*Sonja Brangewitz, Claus-Jochen Haake, Philipp Möhlmeier*

We analyze the stability of networks when two firms strategically form costly links to customers. We interpret these links as customer relationships that enable trade to sell a product. Equilibrium prices and equilibrium quantities are determined endogenously for a given network of customer relationships. We investigate in how far the degree of substitutability of the firms' products and the costs of link formation influence the equilibrium profits and thus have an impact on the

incentives to strategically form relationships to customers. For networks with  $n$  customers we analyze local stability regions for selected networks and determine their limits when  $n$  goes to infinity. It turns out that the shape of local stability regions for those networks does not significantly change compared to a setting with a small number of customers. In addition, we establish the existence of locally stable networks for complementary or independent products. More precisely, for these products either the empty, the complete or both networks are locally stable. We also relate local and Nash stability for selected networks with  $n$  customers. For networks with three customers we characterize locally stable networks. In particular, existence is guaranteed for any degree of substitutability.

## ■ TB-06

Thursday, 11:00-12:30 - Hörsaal 5

### Robust Revenue Management

Stream: Pricing and Revenue Management

Chair: *Jochen Gönsch*

#### 1 - Multi-criteria Optimization for Airline Revenue Management

*Felix Geyer, Catherine Cleophas*

Thus far, most airline revenue management research focuses on maximizing expected short-term revenue. However, from a business perspective, other success criteria can play a significant role, such as market share or average load factor. These indicators are believed to improve the airline's stock market value and its long-term market. In practice, this discrepancy causes revenue optimal solutions – as calculated by automated systems – to be manually overruled by airline analysts. However, such manual interventions come at the risk of collateral damage. To avoid this, we suggest to add additional criteria to the revenue optimization problem's objective function. We formulate a multi-criteria revenue management model and present a dynamic programming approach to solve it. The resulting efficient frontier can be used by decision makers to find a favorable trade-off between revenue and secondary goals.

#### 2 - Practical Decision Rules for Risk-Averse Revenue Management using Simulation-Based Optimization

*Jochen Gönsch, Sebastian Koch, Michael Hassler, Robert Klein*

In practice, human-decision makers often feel uncomfortable with the risk-neutral revenue management systems' output. Reasons include a low number of repetitions of similar events, a critical impact of the achieved revenue for economic survival, or simply business constraints imposed by management. However, solving capacity control problems is a challenging task for many risk measures and the approaches are often not compatible with existing software systems. In this presentation, we propose a flexible framework for risk-averse capacity control under customer choice behavior. Existing risk-neutral decision rules are augmented by the integration of adjustable parameters. Our key idea is the application of simulation-based optimization (SBO) to calibrate these parameters. This allows to easily tailor the resulting capacity control mechanism to almost every risk measure and customer choice behavior. In an extensive simulation study, we analyze the impact of our approach on expected utility, conditional value-at-risk (CVaR), and expected value. The results show a superior performance in comparison to risk-neutral approaches from literature.

## ■ TB-07

Thursday, 11:00-12:30 - Hörsaal 6

### New Results for Shipping, Matching, and Covering

Stream: Graphs and Networks

Chair: *Ralf Borndörfer*



**1 - Integer Programming Formulations and Decomposition Algorithms for Maximum Induced Matching Problem**

*Z. Caner Taşkın, Betül Ahat, Tinaz Ekim*

We investigate the Maximum Induced Matching problem (MIM), which is the problem of finding an induced matching having the largest cardinality on an undirected graph. The problem is known to be NP-hard for general graphs. We first propose a vertex-based integer programming formulation, which is more compact compared to edge-based formulations in the literature. We also introduce vertex- and edge-weighted versions of MIM. We formulate the weighted problem as a quadratic integer programming problem based on our vertex-based formulation. We then linearize our quadratic programming formulation, and propose a decomposition algorithm that exploits a special structure of the linearized formulation. Our computational experiments show that our decomposition approach significantly improves solvability of the problem, especially on dense graphs.

**2 - Optimization Formulations for Set Covering Open Locating Dominating Sets**

*Blair Sweigart, Rex Kincaid*

In this paper we explore various mathematical formulations for extensions on Open Locating Dominating Sets (OLD). OLDs are similar to identifying codes, but on the open neighborhood of the sensor nodes, which adds a layer of robustness. The OLD is a subset of nodes on which we can place sensors that can detect events at nearby nodes, where the subset is such that when an event occurs, we immediately are alerted to the exact location of the event by the sensors that detect it. In a traditional OLD, all nodes must be covered. However, this proves overly restrictive on real-world graphs. For instance, scale-free graphs, with hub and spoke patterns, often have no feasible OLDs because multiple leafs share the same neighborhood. To identify an optimal OLD for these graphs, we merge the traditional formulation with a set covering formulation. We present here linear and non-linear mixed integer binary programming formulations to identify traditional OLDs, OLDs with fixed number of sensors (fixed-p), and maximal set-covering OLDs. We further explore their results on random graphs of various constructs, and the influence of weighting parameters that govern the cost of each sensor and the value of covering certain nodes. We lay the ground work for further application of these formulations to real-world scenarios including actor identification in dark networks and time release contamination in a municipal water supply grid.

**3 - Timetabling on Path Networks with Application to the Istanbul Metrobus**

*Ralf Borndörfer, Oytun Arslan, Ziena Elijazyfer, Hakan Güler, Malte Renken, Guvenc Sahin, Thomas Schlechte*

Bus rapid transit systems in developing and newly industrialized countries often consist of a trunk with a path topology. On this trunk, several overlapping lines are operated which provide direct connections. The demand varies heavily over the day, with morning and afternoon peaks typically in reverse directions. The construction of a timetable for such a system can be seen as a multiperiod covering problem on an interval graph. We study the complexity of this problem, derive some combinatorial properties in the static (or single period) case, consider the clustering of the demand into service periods, and the solution of the multiperiod version. An application to the Metrobus system in Istanbul will be discussed.

**■ TB-08**

*Thursday, 11:00-12:30 - Seminarraum 101/103*

**Collaborative Transportation Planning I (i)**

Stream: Logistics, Routing and Location Planning

Chair: *Kristian Schopka*

Chair: *Mario Ziebuhr*

**1 - Event-Based Support for Collaborative Synchro-Modal Logistics**

*Paul Grefen, Remco Dijkman*

Modern (international) logistics is often of a multi-modal nature, which requires different modes of freight transport used in sequence. Modern logistics must also be flexible to deal with disturbances in

transport, caused for example by traffic or weather conditions, while keeping overall transport times and/or costs as low as possible. This can be accommodated by the use of synchro-modal logistics, i.e., adapting planned transportation modes on-the-fly during the execution of logistics processes. This requires collaborative planning and re-planning based on (near) real-time, detailed transport data produced by a set of transport providers and infrastructure owners. In this presentation, the approach to synchro-modal logistics and real-time planning is presented that has been developed in the GET Service EU FP7 project. This approach is based on highly distributed, real-time generation of detailed, transport-related events and aggregation of these events into high-level information for logistics planners. The GET Service prototype system includes a core platform for logistics information and event processing and includes explicit logistics process execution support. The approach has been evaluated by several case studies in the logistics industry.

**2 - Dynamic Vehicle Routing with Stochastic Travel Times Matrices Changes Induced by a Cooperative Traffic Management**

*Felix Köster, Dirk Christian Mattfeld, Marlin Wolf Ulmer*

Many European cities have experienced an increase in congestion and pollution through the growth of city traffic. To meet a new EU regulation and reduce pollution, cities install dynamic emission-sensitive traffic management systems (TMs). If the air pollution at a supervised pollution hotspots exceeds a threshold, the TMs change traffic infrastructure settings, e.g. traffic lights, to reduce traffic around the particular hotspot. The coordination of settings for a hotspot exceedance is called a "strategy". Each strategy changes the traffic flows in the city and therefore has an individual traffic situation. Courier, express and parcel services (CEP) route vehicles to deliver parcels to customers and are therefore under the influence of traffic management decisions. For CEP's delivery routing, a TMs strategy induces a set of travel times between the customers. This research looks into the possibility of improving CEP routing efficiency, if information about the strategy can be acquired from a cooperative traffic management. A dynamic adaptation of the delivery routes to the new set of travel times and anticipation of future strategy changes is necessary for cost-efficient deliveries. The test instance for this VRP is modeled after the emission-driven traffic management system of Brunswick with a set of emission data. To solve this problem, we introduce a rollout algorithm, which is combined with a commercial solver. The anticipation of future traffic strategy is done by sampling future emission developments. Results show that anticipation and a cooperative traffic management is beneficial for CEP and leads to more efficient routes.

**3 - Request-allocation in Dynamic Collaborative Transportation Planning Problems**

*Kristian Schopka, Herbert Kopfer*

To overcome the uncertainty associated with dynamic transportation planning problems, small and medium sized carriers (SMCs) use auction-based mechanisms to reallocate transportation requests. Game theoretical schemes like the Shapley value ensure a fair cost allocation for individual planning horizons. Nevertheless, shifts in the request-portfolios of the individual SMCs are not taken into account. This issue could cause a collapse of the coalition, particularly when a rolling horizon planning over a long planning period is applied. In this presentation, the winner determination problem is restricted by additional restrictions that ensure an even allocation of transportation requests among SMCs. It means, all SMCs transfer and receive a proportional number of transportation requests through the auction-based request exchange over the considered planning period. In computational experiments, the collaboration profits are analyzed on the dynamic collaborative traveling salesman problem regarding the restricted winner determination problem. Both, the transportation planning problem and the winner determination problem are solved by a mathematical solver, while the calculation of bids is executed by an insertion algorithm.

**■ TB-09**

*Thursday, 11:00-12:30 - Seminarraum 105*

**Algebraic Modeling Languages**

Stream: Software and Modelling Systems

Chair: *Robert Fourer*

## 1 - Cloud services for optimization modeling software

Robert Fourer

Optimization modeling systems first became available online soon after the establishment of the NEOS Server almost 20 years ago. This presentation describes the evolution of NEOS and other options in what came to be known as cloud computing, with emphasis on the modeling aspects of optimization. In comparison to solver services that compute and return optimal solutions, cloud services for building optimization models and reporting results have proved especially challenging to design and deliver. A collaboration between local clients and cloud servers may turn out to provide the best environment for model development.

## 2 - Recent Enhancements in GAMS

Franz Nelissen, Michael Bussieck, Frederik Fiand

Algebraic Modeling Languages (AML) are one of the success stories in Operations Research. GAMS is one of the prominent AMLs and has evolved continuously in response to user requirements, changes in computing environments and advances in the theory and practice of mathematical programming. In this talk we will begin with some fundamental principles and outline several recent enhancements of GAMS supporting efficient and productive development of optimization based decision support applications.

## 3 - Deploying MPL Optimization Models with Google Web Services API's

Bjarni Kristjansson, Sandip Pindoria

Over the past decade the IT has been moving steadfastly towards utilizing software on clouds using Web Services API's. The old standard way of deploying software on standalone computers is slowly going away. Google has been one of the leading software vendors in this area and publishes several web API's which can be quite useful for deploying optimization applications. In this presentation we will demonstrate several Google API's, including the Google Sheets API, Google Maps API, and Google Visualization API and show how they can be integrated with the MPL OptiMax Library for deploying optimization to service both web and mobile clients.

## ■ TB-10

Thursday, 11:00-12:30 - Seminarraum 108

### Multistage uncertain problems

Stream: Optimization under Uncertainty

Chair: Georg Pflug

#### 1 - Multistage Personnel Scheduling under Uncertainty: Evaluating Deterministic Lookahead Policies

Michael Römer, Taieb Mellouli

In this work, we deal with a practical issue arising in personnel scheduling: When constructing a schedule for a given period, one has to consider both past schedules affecting the beginning of the period and, to allow finding high-quality future schedules, anticipate the effect of the schedule on subsequent periods. Note that while these observations typically hold for all types of scheduling, they are particularly important in personnel scheduling due the multitude of rules governing the schedule legality: For example, local rules governing the legality if consecutive pieces of work lead to the fact that the end of the scheduling period has a huge impact on the first days of the following period. In addition, period-transcending rules lead to the fact that in each period (e.g. a week), the effects of a schedule on larger time periods (e.g. months) need to be considered. In particular if the demand in future planning periods is subject to uncertainty, an interesting question is how to account for these effects when optimizing the schedule for a given planning period. The resulting planning problem can be considered as a multistage stochastic optimization problem which can be tackled by different modeling and solution approaches. In this work, we compare deterministic lookahead policies in which a given scheduling period is extended by an artificial lookahead period. In particular, we vary both the length and the way of creating demand forecasts for this lookahead period. The evaluation is carried out using a stochastic simulation in which demands are sampled and the scheduling problems are solved exactly using MILP techniques. Our computational results show that the length of the lookahead period is crucial to find good-quality solutions in the considered setting.

## 2 - Multi-stage Hub-Location Routing Problem

Dimitri Papadimitriou

The Hub-Location Routing Problem (HLRP) combines the Hub Location Problem (HLP) with the Location Routing Problem (LRP). The HLP deals with the design of hub-and-spoke spatial structures to prevent direct point-to-point connections between sources and destinations by introducing distribution, collection and redirection nodes, called hubs, and possibly connections among them called hub edges. On the other hand, the LRP aims at determining the location of facilities, the allocation of demands to facilities, and designing the distribution or collection routes depending on the delivery or assembly properties of the system. The distinctive feature of the HLRP compared to the LRP resides in considering simultaneously both collection or distribution routes (and corresponding routing decisions).

In the context of this paper, hubs provide collective resource abstraction functionality, i.e., the composition and/or aggregation of physical resources offered by individual non-hub facilities (along collection routes), and delivery to customers along distribution routes. This model contrasts with the one considered when each non-hub facility provides such functionality individually and the allocation of demands is performed independently. For this purpose, we introduce a mixed integer formulation covering setting with single- and multi-stage resource composition and/or aggregation. Its properties are then compared against path-, arc- and flow-based formulations considered in the context of multi-level facility-location problems (M(U)FLP). Then, we propose the design a flow-based iterative algorithm for solving this problem efficiently. Finally, we present results of computational experiments to assess its performance on representative settings.

## 3 - Bounds for stochastic multistage optimization problems

Georg Pflug, Francesca Maggioni

Multistage stochastic optimization problems are typically of huge complexity. It is therefore important to obtain quick upper and lower bounds for the optimal value, which allow to decide to stop or to continue with some refinements.

We present bounding methods both for problems already defined on a discrete scenario tree as well as problem which are not yet discretized. In the latter case, we construct approximating scenario trees for which the optimal values are bounds for the true problem. Along with the bounding techniques, we may construct feasible solutions for the true problem, which are epsilon-optimal, with an epsilon, which one may choose.

## ■ TB-11

Thursday, 11:00-12:30 - Seminarraum 110

### Multi-stage Production Systems

Stream: Production and Operations Management

Chair: Peter Greistorfer

#### 1 - Minimizing work-in-process inventory in stochastic and time-dependent flow lines

Justus Arne Schwarz, Raik Stolletz

Flow lines include inventory buffers to compensate stochastic influences such as random processing and repair times. In practice, the parameters characterizing the stochasticity vary over time, for instance, during production ramp-ups. Thus, we introduce a new mechanism for the allocation of inventory buffers in flow lines under stochastic and time-dependent operating environments. In contrast to approaches for systems with time-homogenous parameters, the proposed approach uses information about the future development of the production system to proactively change the maximum inventory level of the buffers over time. We discuss the corresponding decision problem and preliminary results. Differences and commonalities with the buffer allocation problem are outlined.

## 2 - Modelling uncertainty in an automobile multi-stage production process

Andrea Borenich, Peter Greistorfer, Marc Reimann

This work is inspired by a research project with a company from the automobile supplier industry. Such companies frequently have to make bids to obtain production orders. These bids are typically based on cost estimates for a multi-stage production process. In the automobile plant considered, this process involves four stages, namely the stamping plant, the body shop, the paint shop and the final assembly. Additionally, these stages are linked by intra-plant logistics.

We focus on the various options of merging individual decisions taken in the different main stages to highlight the importance of coordinating the cost estimation process. In doing so, we have implemented three strategical model variables. First, each main stage takes an intra-plant location decision, thereby affecting logistics costs. Second, the degree of automation critically influences the volume flexibility within each main stage and drives capital investment. Third, the shift model is the main cause of human resources costs.

The model analysis combines two main questions: how should the cost estimation of the different main stages be organized to obtain an overall acceptable result and how should the firm handle the risk, induced by the cost estimation under input parameter uncertainty? The organizational question is addressed by comparing three different approaches. The first one imitates the current practice of our industrial partner. The second one considers a central authority taking all decisions. Finally, the third one sequences the main stages' decisions. Our answer to the risk question is a comparison of a deterministic approach with two stochastic approaches, where uncertainty in the parameters is modelled through scenarios. The resulting MILPs are solved with CPLEX.

Capacity can be increased in channel sharing HetNets by intelligently scheduling User Equipments to receive data from Small Cells. Grammar-based Genetic Programming (GBGP) has been shown to be a powerful framework for automatically devising Small Cell scheduling heuristics. In previous works, the single best model from many independent runs constituted the solution. This approach is naive because all but one of the evolved models are discarded. An ensemble technique which exercises  $N=25$  models from a single run is proposed in this paper. Schedules must be generated at the beginning of every 40 ms 'frame' based on measurement reports assimilated over the previous frame. The ensemble generates  $N$  hypothesis schedules based on the measurement reports in frame  $t$ . Each hypothesis is rapidly evaluated with respect to a utility of downlink rates. The best performing schedule is executed in frame  $t+1$ .

Simulations reveal that the proposed ensemble method significantly outperforms the naive approach and a state of the art benchmark scheme, at a significance level of  $\alpha=0.01$ . In fact, the ensemble is within 11% of the best known optimum given by CMA-ES. Semantic analysis reveals that evolved GBGP phenotypes generate highly dissimilar schedules. Such strategic diversity enables the ensemble to specialise on particular cases. A single generalised model cannot achieve a comparable degree of specialisation.

## 3 - Don't buy a pig in a poke: Supporting allocation decisions in multi-clouds

Leonard Heilig, Eduardo Lalla-Ruiz, Stefan Voss

The rise of cloud computing in recent years led to a plethora of different cloud services designed to be adapted to the individual resource demands and requirements of consumers. In multi-clouds, infrastructure as a service (IaaS) solutions are offered by multiple cloud providers and need to be combined and configured in such a way that individual cost and performance goals of consumers can be achieved. Due to the specific characteristics of multi-clouds, complex decision problems arise and need to be efficiently addressed for supporting decision makers in purchasing those cloud services. In this work, we propose a cloud brokerage approach to facilitate purchasing and scheduling decision processes for IaaS services under several rich constraints. In doing so, we model the problem and generate different problem instances consisting of various consumer and resource requirements in order to assess the quality and implications of our proposed mechanism.

## ■ TB-12

Thursday, 11:00-12:30 - Seminarraum 202

### Scheduling and Sequencing: Applications

Stream: Metaheuristics

Chair: Franz Rothlauf

#### 1 - A Heuristic Procedure for Integrated Cutting Stock and Sequencing Problem in the Marble Industry

Burcu Kubur, Adil Baykasoglu

In this study, we deal with knife dependent setup cost of one dimensional cutting stock problem with usable leftover (1DCSPUL) which is a specific case of the well-known one dimensional cutting stock problem (1DCSP). Even though the literature in the area of cutting and packing is growing rapidly, research seems mostly to focus on standard problem, while the practical aspects are less frequently dealt with. Despite its great applicability in several industries, this is particularly true for the combined cutting stock and sequencing problem because of its great complexity. In industrial cutting processes setup cost occur whenever changing over one cutting pattern to another and the cutting equipment has to be prepared in order to meet technical requirements of the new pattern. Setups involve the consumption of the resources and the loss of production time capacity. Therefore, cutting stock problem and sequencing problem have to be simultaneously considered in a cutting process. The goal here is to minimize transportation, overgrading and knife dependent setup costs. The main endeavor of this study is to specifically developed Stochastic Diffusion Search Algorithm (SDS) to solve the 1DCSPUL by taking into sequence dependent setups cost between cutting marble blocks. Computational experiments are conducted to assess the performance of the proposed heuristic by solving randomly generated instances and also practical instance from a marble company.

#### 2 - Ensemble Techniques for Scheduling in Heterogeneous Wireless Communications Networks

David Lynch, Michael Fenton, Stepan Kucera, Holger Claussen, Michael O'Neill

Cellular network operators are struggling to cope with exponentially increasing demand. Heterogeneous Networks (HetNets) have been proposed as a means of increasing capacity without the need for additional bandwidth, which is expensive and scarce. HetNets consist of traditional high-powered Macro Cells supplemented with low-powered Small Cells.

## ■ TB-13

Thursday, 11:00-12:30 - Seminarraum 204

### Simulation Models I

Stream: Simulation and Stochastic Modeling

Chair: Brigitte Werners

#### 1 - A macroscopic simulation model of the urban Viennese subway network with capacity constraints and time-dependent demand

David Schmaranzer, Roland Braune, Karl Doerner

We present a discrete event simulation model of the Viennese urban subway network with capacity constraints and time-dependent demand. Demand, passenger transfer and travel times as well as vehicle travel and turning maneuver times are stochastic. Capacity restrictions apply to the number of waiting passengers at a platform and within a vehicle. Passenger generation is a time-dependent Poisson process which uses hourly origin-destination-matrices based on mobile phone data. A statistical analysis of vehicle data revealed that vehicle interstation travel times are not time- but direction-dependent. The purpose of this model is to support strategic decision making by performing what-if-scenarios to gain managerial insights. Such decisions involve how many vehicles may be needed to achieve certain headways and what are entailed consequences. Headway optimization, for example, is a significant subject in urban public transportation: Population growth - a prognosis expects the Viennese population (currently 1.78 millions) to break the 2 million mark by 2027 - as well as other reasons (e.g. efforts to reduce carbon emissions) call for frequent reevaluations whether provisions are - now or in future - indispensable. Economic factors namely, capital and operational expenditure (e.g. daily fleet size as well as driver headcount, infrastructure preservation and potential expansion) - are contrary to the goal of passenger satisfaction (i.e. service level, travel time, etc.). Our first results allow for bottleneck identification as well as a sensitivity analysis.

**2 - Decision support for power plant shift configuration using stochastic simulation**

*Pia Mareike Steenweg, Matthias Schacht, Brigitte Werners*

Power generation companies have to ensure a secure supply of power to their customers at any time. Hence, appropriate personnel support has to be guaranteed. The application context implies that all business functions with varying qualification requirements have to be staffed at any time. In this regard, optimal shift scheduling is a highly important and complex task. For the purpose of comparing different proposed shift configurations, we conceptualise a simulation tool with a reactive structure incorporating an integer optimisation model. The stochastic simulation takes uncertainty associated with employee sickness into account. The optimisation model assigns business functions, whereby the reactive character requires a renewed allocation on each simulated day to cope with unexpected changes of employee absence. We analyse the reliability, the assigning-quality and the practicability of the shift designs. Additionally, the fairness between employees is a significant evaluation criteria. A case study for a German power generation company is carried out. The specifics of two proposed designs (a 4-shift and a 5-shift configuration) are analysed. Following the extensive stochastic simulation based on realistic data, we compare the designs regarding different evaluation criteria. The trade-off between company and workforce preferences is discussed in detail to provide a reasonable guidance for decision support.

**3 - Simulating the diffusion of competing technology generations: An agent-based model and its application to the consumer computer market in Germany**

*Markus Günther, Christian Stummer*

Consumer adoption of innovations is a key concern for strategic management in many companies, as adoption ultimately drives the market success of new products. Due to the inherent complexity of adoption processes arising from the underlying social system (i.e., the respective consumer market), analytical approaches more often than not fail at properly capturing the emergent market behavior. Agent-based modeling and simulation, on the other hand, allows for considering various inherent, underlying social influences as well as spatial and temporal aspects and have already shown promising results in these respects. Markets in which not just two, but multiple and successively introduced technology generations compete against each other, constitute a special case. Our agent-based model contributes to this field of technology diffusion research in that it accounts for novel and advanced product features in each technology generation, the reluctance of (some) users to switch to a new (yet unfamiliar) technology, and various social influences between consumers. Based on data from several sources, the model is calibrated for the German consumer computer market from 1994-2013. Since simulation results indeed replicate the actual development of market shares on monthly bases, we can demonstrate the applicability of such an agent-based approach in principal. More work needs to be done, particularly with respect to preference elicitation for product features that currently are widely unknown by regular consumers, before the simulation will also be ready for being applied for predicting the market diffusion of forthcoming technology generations. Still, our approach takes a step further toward simulation-based decision support for forecasting technology diffusion.

of projects and criteria is large, the efficiency of the resource allocation and the quality of the decision making process requires a suitable systematic approach. Hence, this study proposes a Stochastic Multicriteria Acceptability Analysis (SMAA) based approach for project portfolio selection. Thereby, a multi-criteria evaluation is carried out using SMAA method in order to evaluate each project individually based on various criteria. Based on this, a linear programming model is applied to maximize the total value of the projects selected for the optimal portfolio while ensuring some constraints related to the resources available. The proposed approach can provide a scientific basis for oil and gas companies to make robust decisions based on uncertain and incomplete information. It also helps to decrease the subjective blindness in the investments, and to save cost and time in data elicitation process. Finally, an example case study of exploration project portfolio selection in oil and gas industry is carried out to illustrate the proposed approach.

**2 - Self-regulated Multi-criteria Decision Analysis**

*Muhammad Umer Wasim, Pascal Bouvry, Tadas Limba*

Multi-criteria Decision Analysis (MCDA) ranks different alternatives during the decision making process according to given criteria by a decision maker. However, the evaluation of available alternatives is prone to bias if decision maker has insufficient domain knowledge. The decision maker may exclude relevant or include irrelevant criterion termed as 'misspecification of criteria'. This causes structural uncertainty within the MCDA leading to suboptimal or least optimal selection of an alternative. To cater such issue, we propose a self-regulated MCDA, which uses notion of factor analysis from the field of statistic. A proof of concept example using dataset on Quality of Service (QoS) by online Cloud storage provider was used to illustrate in-field execution. The criteria of QoS in the dataset were: Availability, Response Time, Price, Speed, Storage Space, Ease of Use, Technical Support, and Customer Service. The results showed that, in the given dataset, Storage Space is an irrelevant criterion and the rest account for more than 95% of change in the QoS, which endorse their presence as relevant criteria. In the next stage of this research, our goal is to implement and test self-regulated MCDA for structural uncertainty in Cloud Brokerage Architecture that often uses MCDA for retailing of Cloud services. The beneficiary of the research would be enterprises that view insufficient domain knowledge as a limiting factor for acquisition of Cloud services.

**3 - Dynamic capabilities in new product development and its effects on firm performance**

*Mohammad Darvizeh, Jian-Bo Yang, Steve Eldridge*

In dynamically competitive environment, it would be influential to examine the relationship between dynamic capabilities (DC) and the superior performance of firms through new product development (NPD) performance and this enable managers to make a sound and quick decision. While differential performances of firms in the high technology industry such as automotive or aerospace industry are so important for achieving sustainable competitive advantage, the study searches for the explanation of this phenomenon in the view of dynamic capabilities. Through a comparative multi cases study of fairly large R&D intensive manufacturing firms, the analysis focuses on identifying and evaluating the effects of organisational and managerial processes on the development of three capacities of sensing, seizing and reconfiguration that form dynamic capabilities through product development activities. While dynamic capability facilitates an effective and efficient product development, the integrated findings of the analysis is to show the performance assessment of dynamic capability using multi criteria decision analysis (MCDA) that determines the success and failure of manufacturing buyer's firms in the recent volatile environment. The results contribute to the literature by verifying the conceptual framework of foundations and micro-foundations of dynamic capabilities, illustrating the transformation of its multiple roles, and introducing an extended framework for managerial actions. Most importantly, this research confirms that the superior performance of a company in the automotive or aerospace industry is best explained by the theory of dynamic capabilities. In short, the research provides an insight for managers to define relevant NPD strategies.

**■ TB-14**

*Thursday, 11:00-12:30 - Seminarraum 206*

**Decision Making with Incomplete or Imprecise Information**

Stream: Decision Theory and Multiple Criteria Decision Making

Chair: *Mohammad Darvizeh*

**1 - SMAA-Based Approach for Project Portfolio Selection with Uncertain and Incomplete Information**

*Makbule Kandakoglu, Grit Walther*

Choosing the optimal project portfolio from a set of alternative projects is a critical decision for oil and gas companies. This significant decision is often complicated in practical applications due to the uncertainty associated with the value of projects and incomplete preference information on the evaluation criteria. Especially when the number

**■ TB-15**

*Thursday, 11:00-12:30 - Seminarraum 305*

**Ressource Constrained Project Scheduling**

Stream: Project Management and Scheduling

Chair: *Kristina Bayer*

### 1 - A decomposition method for the Multi-Mode Resource-Constrained Multi-Project Scheduling Problem (MRCMPSP)

*Mathias Kühn, Sebastian Dirkmann, Michael Völker, Thorsten Schmidt*

Multi-Mode Resource-Constrained Multi-Project Scheduling Problems (MRCMPSP) with large solution search spaces, commonly realized in assembly planning of aircrafts (up to 20.000 activities), cannot be optimized in an acceptable computation time. In this paper, we have focused on decomposition strategies for such large scale problems. Based on literature review, a time-based decomposition approach was adopted for the present problem. With time-based decomposition approaches a schedule is divided into several time periods. All activities in a time period describe an independent problem, termed as a sub-problem. Although state-of-the-art research in the area of time-based decomposition approaches provides reduction in computation time for the Resource-Constrained Project Scheduling Problem (RCPSP), application of these concepts on MRCMPSP was observed to provide inefficient results. Due to the independent optimization of these sub-problems project information regarding the relationships among activities in different time periods is not considered. This loss of information has a negative impact on the overall solution quality. We developed a decomposition strategy to improve the interactions between the sub-problems for a better target performance while reducing the computation time. Based on an initial solution the sub-problems are created and sequentially optimized in a concept similar to rolling horizon heuristics. We introduce a crossover with a constant and a variable component at the end of each partial schedule to improve the interactions among sub-problems and thus taking the volatile nature of the examined problems into account. In comparison, our approach proved to provide significant improvements in runtime and target performance.

### 2 - Solving the resource-constrained multi-project scheduling problem with a flexible project structure

*Luise-Sophie Hoffmann, Carolin Kellenbrink*

In flexible projects, jobs that have to be scheduled are not fully known in advance. Hence, in addition to scheduling, the project structure needs to be determined. The resource-constrained project scheduling problem with a flexible project structure (RCPSP-PS) deals with this problem. In application fields such as the regeneration of complex capital goods, multiple projects use the same renewable and non-renewable resources. Therefore, they have to be planned simultaneously. In this talk, the RCPSP-PS is extended to the RCMPSP-PS with the goal of minimizing the total costs consisting of job costs and penalties for delay. For the purpose of solving flexible multi-projects in practice-oriented project sizes, different heuristic methods are considered. A two staged priority rule-based method is presented in which firstly the project structure is fixed and secondly the selected jobs are scheduled. Furthermore, genetic algorithms with different solution encodings are presented. A comparative study indicates the performance of the heuristic and the exact methods.

### 3 - Monte Carlo Tree Search for the Resource-Constrained Project Scheduling Problem

*Kristina Bayer, Robert Klein, Sebastian Koch*

Monte Carlo Tree Search (MCTS) is a heuristic algorithm from the field of Artificial Intelligence combining classical tree search with Monte Carlo simulations. It is therefore suited for problems that can be represented as trees of sequential decisions. MCTS has recently attracted a lot of attention because of its success in the board game Go. However, little research has been done investigating the suitability of MCTS for planning problems of Operations Research. In this talk, we adapt MCTS to the well-known Resource-Constrained Project Scheduling Problem (RCPSP). In particular, we show how to appropriately define and search tree representations of the RCPSP. We conduct a number of computational experiments on standard RCPSP data sets from the literature to investigate the applicability and performance of our approaches.

## ■ TB-16

Thursday, 11:00-12:30 - Seminarraum 308

### Resource scheduling

Stream: Health Care Management

Chair: *Melanie Erhard*

### 1 - Queue management for operating theatres

*Belinda Spratt, Erhan Kozan*

Australian public hospitals are facing an increase in the demand for elective surgeries due to a number of factors including the aging population and improved access to diagnostic tools. It is important to ensure that the current hospital infrastructure is being utilised efficiently so as to combat the increase in demand. We propose a Mixed Integer Non-Linear Programming (MINLP) formulation for the combined master surgical scheduling problem (MSSP) and surgical case assignment problem (SCAP) under a block scheduling policy. This is the problem of assigning specialties, surgeons and patients to operating theatre time blocks. Inspired by a case study of a large Australian public hospital, we incorporate stochastic surgical durations, surgeon and theatre capability and availability, and current government policy aimed at reducing elective surgery waiting times for public patients. Due to the size of the case study considered, we use a number of meta-heuristics inspired by Simulated Annealing (SA) and Reduced Variable Neighbourhood Search (RVNS). Based on a real world case study, we validate the proposed approach which promises to significantly improve the efficiency of operating theatre scheduling.

### 2 - Optimizing Intensive Care Unit (ICU) Planning by Markov Decision Process

*Jie Bai, Jens Brunner*

Intensive care units (ICU) are known as a crucial and expensive resource largely affected by uncertainty and variability. As a result, the capacity is often limited causing many negative effects for the ICU itself, and even making ICU a bottleneck in hospital patient flows. To solve this problem, both admission control of newly arrival patients and demand driven discharge of currently residing patients could be options. However, the rejection of new patients could increase the mortality rate, and the demand driven discharge might cause the patient health deterioration and then resulting in readmission. We use the discrete time Markov decision process (MDP) to model the optimal decision making problem in such a complex system. Both exact solution and approximate solution approaches are applied. We analyze the performance of the model by a case study based on empirical data.

### 3 - Flexible break assignment in physician scheduling

*Melanie Erhard, Jens Brunner*

In hospitals, personnel generates the biggest and most important cost. This research focuses on physician scheduling in hospitals with the main objective to investigate break assignment in the scheduling process. In particular, we consider three different approaches for modeling the flexible placement of breaks. Current scheduling literature mainly neglects the consideration of breaks whereas practice uses manual approaches that are time and cost intensive. Focusing on a strategic planning problem, we minimize the number of assigned physicians subject to demand coverage and labor regulations. We formulate the problem as a mixed-integer program and test various parameter settings. The problem is solved with standard software (like CPLEX). For our experimental study, real world data from a large hospital in Germany is used. Results show that consideration of breaks has little impact on the workforce size but ensures legal regulated rest periods for physicians.

## ■ TB-17

Thursday, 11:00-12:30 - Seminarraum 310

### Coordination and Collaboration

Stream: Supply Chain Management

Chair: *Thomas Spengler*

### 1 - Partial Cooperation Opportunities in a Two-Echelon Supply Chain

*Ismail Serdar Bakal, Betül Diler, Ozgen Karaer*

In this study, we consider a two-echelon supply consisting of two manufacturers and a single retailer. Each manufacturer produces a single product, and the products are substitutable. The demand for the products is random. Before the retailer determines the order quantities, the manufacturers set their wholesale prices simultaneously. In this setting, we consider the decentralized setting where each party acts independently, and model the vertical competition between the retailer and the manufacturers as well as the horizontal competition between

the manufacturers. We first characterize the order quantities of the retailer. Then, we consider the pricing problem of the manufacturers and determine the equilibrium wholesale prices. We also consider the setting where the prices are determined sequentially. We next consider different alternatives for cooperation. We first investigate the retailer's choice in forming a coalition with one of the manufacturers and observe its effects on the ordering decisions. Then, we aim to quantify the benefits that the manufacturers can generate by coordinating their pricing decision.

## 2 - Drivers and Resistors for Supply Chain Collaboration

*Verena Jung, Tjark Vredevelde, Marianne Peeters*

In the last decades companies have been realizing the need for looking outside their organizational boundaries for new opportunities. This is due to various factors such as a constantly growing competition amongst organizations, rising globalization, a growing product variety and a wide access to sophisticated IT and web-based technologies. According to Sukati et al. (2012) and Horvath (2001) a new vital base of competitive advantage, that has not yet been fully exploited and thus offers a huge potential for growth and performance improvements, is supply chain collaboration (SCC). Although the idea of SCC may sound easy in theory collaborations in practice often fail, which indicates a gap between theory and practice. This is due to the fact that for a specific SCC a huge amount of drivers and resistors has to be taken into account by all parties involved. However, these drivers and resistors are often unknown or misunderstood by the participants. Despite of the fact that a great amount of research has been published in that field, the literature shows a great amount of ambiguity. With this paper a clear structure for the drivers and resistors is provided, which will close the gap between theory and practice and thus lead to more successful SCCs. This helps to understand for example differences in what are the important drivers and resistors for a certain kind of relationship. Preliminary results show that the structure can help to identify important drivers and resistors for the different parties even in a more complex triangular relationship.

## 3 - Coordination by contracts in distributed product development processes with complete substitution

*Kerstin Schmidt, Thomas Volling, Thomas Spengler*

In distributed product development processes system integrators collaborate with suppliers to provide marketable products. Considering a converging supply chain with two suppliers and one system integrator, we apply a Stackelberg game to model the contract-based coordination of such processes under uncertain development results, complete substitution and maximum price clause. Assuming uniformly distributed development results, we analyze the coordination ability of a wholesale price contract and a penalty contract and present numerical illustrations of centralized and decentralized solutions.

## ■ TB-18

Thursday, 11:00-12:30 - Seminarraum 401/402

### Container and Terminal Operations II (i)

Stream: Logistics, Routing and Location Planning

Chair: *Julia Funke*

#### 1 - Optimal dynamic assignment of internal vehicle fleet at a maritime rail terminal with uncertain processing times

*Ying Xie, Dongping Song*

The growing traffic volume puts a huge pressure on container port as an interface between seaborne transport and hinterland transport. The deployment of mega-vessels has added further challenges to container ports to cope with the surge effect of container flows. In addition, traffic congestion and emissions caused by truck movements in the surrounding area of seaports have raised serious concerns to the society. Rail transport is regarded as an effective way to tackle the above challenges due to its high capability and low emission. Therefore, improving the efficiency of rail terminal operations at seaports is essential to ensure the sustainability of global container transport chains. This study aims to investigate and improve the efficiency of container loading process at a seaport by optimising the container pre-staging and flow rates in the process of moving containers from storage yards to the train. We will formulate the problem into a stochastic dynamic

programming model. The decision variables include: the pre-staged number of containers from storage yard to rail terminal buffer; the dynamic flow rates from yard to buffer and the dynamic flow rates from buffer to the train within the time window. A case study will be constructed based on the data from a real container rail terminal. Numerical experiments will be performed to illustrate the effectiveness and the sensitivity of the model and the results. Our model is able to balance the container pre-staging decision and the container flow rate control within the time window. In addition, the model can dynamically determine the optimal container flow rates from storage yard to rail terminal buffer and from rail terminal buffer to the train by taking into account the uncertainties in the handling activities.

#### 2 - Cargo Allocation and Vessel Scheduling Problem with Synchronization of Transshipments

*Sel Ozcan, Deniz Türsel Eliiyi*

Among various seaborne transportation alternatives for containers, liner shipping is preferred mostly as it offers cheaper freight rates, higher safety level and less environmental hazard. For providing a better service to its customers, liner shipping companies try to design their services by offering low operating costs, high frequencies, fast transit times, and both tight and reliable voyage schedules to their clients. Major customers of liner shipping companies are freight forwarders, who are responsible for the organization of the shipments by arranging the routing of cargo bookings using one or more carriers. Hence, a freight forwarder may direct flows along several paths by indirect routing via transshipments at hubs. In addition to providing cheap transportation solutions, freight forwarders should offer high service levels to their clients by providing on time delivery of cargo bookings for gaining a competitive edge. Our study focuses on the allocation of cargo bookings to predetermined routes where each route consists of various services and each service is operated by vessels of different liner shipping companies. The objective is to minimize cost of the freight forwarder, which has its own fleet and also acts one of the liner shipping companies operating on the complete network. The considered problem concentrates on achieving the on-time deliveries of cargo bookings through synchronization of transshipment operations at an operational level, as well as by minimizing the deviations of the freight forwarder's vessels from their planned schedules. A novel MILP model is presented and its performance is tested over benchmark instances.

## ■ TB-19

Thursday, 11:00-12:30 - Seminarraum 403

### Learning Robust Routes (i)

Stream: Traffic and Passenger Transportation

Chair: *Matúš Mihalák*

#### 1 - Robust Routing in Urban Public Transportation: How to find reliable journeys based on past observations

*Tobias Pröger, Katerina Böhmova, Matúš Mihalák, Peter Widmayer*

We study the problem of robust routing in urban public transportation networks. In order to propose solutions that are robust for typical delays, we assume that we have past observations of real traffic situations available. In particular, we assume that we have "daily records" containing the observed travel times in the whole network for a few past days. We introduce a new concept to express a solution that is feasible in any record of a given public transportation network. We adapt the method of Buhmann et al. (2013) for optimization under uncertainty, and develop algorithms that allow its application for finding a robust journey from a given source to a given destination, and propose possible generalizations. The robust routing concepts presented in this work are suited specially for public transportation networks of large cities that lack clear hierarchical structure and contain services that run with high frequencies.

#### 2 - Robust Routing in Urban Public Transportation: Evaluating Strategies that Learn from the Past

*Katerina Böhmova, Matúš Mihalák, Peggy Neubert, Tobias Pröger, Peter Widmayer*

Given an urban public transportation network and historic delay information, we consider the problem of computing reliable journeys. We propose new algorithms based on our recently presented solution concept (Böhmová et al., ATMOS 2013), and perform an experimental evaluation using real-world delay data from Zürich, Switzerland. We compare these methods to natural approaches as well as to our recently

proposed method which can also be used to measure typicality of past observations. Moreover, we demonstrate how this measure relates to the predictive quality of the individual methods. In particular, if the past observations are typical, then the learning-based methods are able to produce solutions that perform well on typical days, even in the presence of large delays.

### 3 - Bi-directional Search for Min-Max-Relative-Regret Routes in Time-dependent Bi-criteria Road Networks *Matúš Mihalák, Sandro Montanari*

Based on time-dependent travel times for  $N$  past days, we consider the computation of robust routes according to the min-max relative regret criterion. For this method we seek a path minimizing its maximum weight in any one of the  $N$  days, normalized by the weight of an optimum for the respective day. In order to speed-up this computationally demanding approach, we observe that its output belongs to the Pareto front of the network with time-dependent multi-criteria edge weights. We adapt a well-known algorithm for computing Pareto fronts in time-dependent graphs and apply the bi-directional search technique to it. We also show how to parametrize this algorithm by a value  $K$  to compute a  $K$ -approximate Pareto front. An experimental evaluation for the cases  $N = 2$  and  $N = 3$  indicates a considerable speed-up of the bi-directional search over the uni-directional.

## ■ TB-20

Thursday, 11:00-12:30 - Seminarraum 404

### Analytics in Mobility

Stream: Business Analytics and Forecasting

Chair: *Jennifer Schoch*

#### 1 - Accounting for Range Anxiety in Smart Charging Strategies for Electric Vehicles

*Jennifer Schoch, Johannes Gärtner, Alexander Schuller, Thomas Setzer*

Electric vehicles (EVs) can considerably contribute to the reduction of global CO<sub>2</sub> emissions and are a promising alternative for conventionally propelled vehicles. One of the primary factors limiting a broader and faster distribution of EVs is the energy storage system, i.e., the high voltage battery. While the battery capacity is limited by the high cost per kWh as well as its weight, the range of a compact EV is considerably lower than that of vehicles with an internal combustion engine.

Empirical studies of charging behavior of EV drivers reveal that they often experience range anxiety resulting in a diurnal full re-charging of the battery to maximize a vehicle's range available.

While the operative SoC range strongly impacts battery degradation in terms of capacity fade and the resulting range decline, it has been shown that the time to end of life (EoL) can be considerably increased by applying the degradation optimal charging strategy. However, the optimal point of operation in terms of SoC range implies a minimization of available range, in contrast to full-charging where the available range is maximized.

Hence, there is a clear trade-off to be solved regarding short and long term objectives. In order to analyze the trade-off between both strategies, we evaluate the degradation optimal charging strategy and the influence on battery life prolongation resulting from the establishment of different levels of range buffers. The time to end of life influenced by different charging strategies and range buffers is evaluated using simulation based analysis based on more than 1000 empirically-derived driving profiles.

#### 2 - Towards mathematical programming methods for predicting user mobility in mobile networks

*Alberto Ceselli, Marco Premoli*

Motivated by optimal orchestration of virtual machines in a mobile cloud computing environment to support mobile users, we face the problem of retrieving user trajectories in urban areas. We partition the region covered by a mobile network into cells, one for each access point, and we suppose to be given: (a) the adjacency matrix between cells, and (b) the demand in each cell at each point in time, that is the number of users connected to the corresponding access point. We also assume that an aggregated information about user mobility is given, like the probability distribution of trajectory lengths. Our aim is to

find an estimate on the trajectory of each user, in terms of sequence of cells traversed during the considered time horizon. Our modeling approach is the following: first, we perform both a time and a trajectory length discretization. Then, we introduce extended mathematical programming formulations, inspired by flows over time models, having a polynomial number of constraints, but an exponential number of variables. We include two hierarchical objectives and we experiment on two forms of flow balancing constraints. We devise column generation algorithms: pricing turns out to be a resource constrained shortest path problem, for which we provide an ad-hoc dynamic programming procedure. We experiment on both synthetic datasets, obtained through generative models from the literature, and real world datasets from a major mobile carrier in Paris for which ground truth is not available. Our methods turn out to be accurate enough to predict mobility on the synthetic datasets, and efficient enough to tackle real world instances; while fine time discretization increases their effort, fine length discretization is not an issue.

#### 3 - Simulation-based Data Selection and Reduction for Battery Degradation Modeling in Electric Vehicles

*Philipp Staudt, Jennifer Schoch*

Traction batteries are one of the most cost intensive components of electric vehicles (EV) and therefore limit their driving range. Due to battery degradation and the resulting capacity fade, this phenomenon is amplified. The influence of usage patterns on degradation has not been fully investigated by now and sufficiently detailed field data is not yet available. Consequently, OEMs are facing the challenge of selecting and reducing the relevant features of the potentially vast amount of data created by electric vehicles in the field in order to optimize the ratio of information gained and the data volume transmitted.

To address this challenge, a simulation-based analysis is conducted, which captures the influence of the dynamic user behavior and the resulting degradation on EV batteries. The simulation is based on a realistic aging model and more than 1000 representative driving profiles. By means of variable selection using Lasso regression and dimension reduction techniques, such as PCA, different forecasting models are developed. Furthermore, the trade-off between forecasting ability and the required data volume is evaluated. Additionally, the models are tested for their ability to predict the battery's end-of-life. We find that by using a small amount of data, which is suitable for mobile transmission, a satisfactory forecasting accuracy can be achieved. All developed models use driving behavior features as input factors. This suggests changes in the warranty design of OEMs. Furthermore, the results of the end-of-life prediction are promising regarding a predictive maintenance strategy.

## ■ TB-21

Thursday, 11:00-12:30 - Seminarraum 405/406

### Facility and Hub Location Problems

Stream: Logistics, Routing and Location Planning

Chair: *Teresa Melo*

#### 1 - The stochastic single allocation hub location problem

*Nicolas Kämmerling, Borzou Rostami*

The design of hub-and-spoke transport networks is a strategic planning problem as the choice of hub locations has to remain unchanged for long time periods. The future transport volumes are not known in advance and can only be estimated by a stochastic distribution during the planning process. Moreover, the demand in transport networks changes dynamically over the time due to seasonal effects. This paper considers the inclusion of uncertainty to the single allocation hub location problem. From the deterministic problem we derive two stochastic two-stage program formulations for the problem where the allocation to the hubs can be viewed as either fixed or flexible over the time. In case of fixed allocation pattern we observe that all structural decision are taken within the strategic planning phase. In fact we show that the stochastic single allocation hub location problem is equivalent to the deterministic problem where the average demand values are taken as input data. In case of flexible allocation pattern the resulting optimization problem is significantly harder as allocation decision depends on the current demand. We develop a dual decomposition procedure which unifies the hub location choice after having decomposed the problem into a set of independent subproblems.

## 2 - Competitive hub location for the leader; considering followers in the future

*Babak Farhang Moghaddam, Amir Afshin Fatahi*

This research addresses the hub location problem in competitive markets. From the view point of the company that has entered the market for the first time (the leader), hub location aims at: 1) meeting the market demand fully with the least possible costs, and 2) reducing the expected profits of those companies that want to enter the market in the future (the followers). A two steps algorithm has been proposed to solve such a competitive hub location problem. The market shares of the leader and followers are determined based on their announced prices and the rate customers are sensitive to them, and then each company's profit is calculated. This research studies Iran's airlines market in 2013, analyzes the elements that affect location through adjusting the problem parameters under different conditions, and solves the problem by the dynamic programming exact method. The results have shown that a jump (turning) point is possible in the profit reduction rate of the competing companies with respect to the number of the hubs of the leader. Also, using the regression analysis, the effects of the model parameters on the companies' maximum profits have been tested.

## 3 - Multi-period facility location with dynamic capacity planning and delayed demand satisfaction

*Teresa Melo, Isabel Correia*

We consider a facility location problem that takes into account changing trends in customer demand and costs. To this end, facilities may have their capacities dynamically adjusted over a planning horizon. It is assumed that a set of existing facilities are operating with given capacities. These facilities can be removed, expanded and/or contracted over the time horizon. Once removed, a facility cannot be reopened. Additionally, a set of potential locations for establishing new facilities is also considered. Once a new facility has been installed, its configuration may be modified through capacity expansion and/or contraction over multiple periods. New facilities must remain open until the end of the time horizon. Our problem setting addresses situations in which space and equipment can be rented or operations can be subcontracted. This allows a company to dynamically adjust the configuration of its facilities, e.g. to respond to seasonal demand trends. A further distinctive feature of our problem is that two customer segments are considered with different sensitivity to delivery lead times. Customers in the first segment require timely demand satisfaction, whereas customers in the second segment tolerate late deliveries. A tardiness penalty is incurred to each unit of demand that is satisfied with delay. We develop alternative mixed-integer linear programming models to redesign the facility network so as to minimize the total cost. Additional inequalities are proposed to enhance the original formulations. A computational study is performed with randomly generated instances and using a general-purpose solver. Useful insights are derived from analyzing the impact of different demand patterns and delivery lead time restrictions on the network structure and total cost.

## Thursday, 13:30-14:15

### ■ TC-02

*Thursday, 13:30-14:15 - Hörsaal 1*

### Semi-Plenary Walther

Stream: Semi-Plenaries

Chair: *Stefan Wolfgang Pickl*

#### 1 - OR for Future Mobility: Designing Sustainable Means of Transportation

*Grit Walther*

The transportation sector contributes significantly to global fossil CO<sub>2</sub> emissions, and is still almost totally reliant on petroleum-derived fuels. Therefore, a transformation is needed and sustainable means of transportation have to be launched and disseminated. In this context, strategic investment decisions have to be taken, e.g. regarding the installation of charging infrastructure for battery electric vehicles or the design of production networks and supply chains for biofuels and E-fuels. Additionally, complex planning problems arise at an operational level, e.g. by routing battery electric vehicles with limited range and need for (partial) recharging in a still scarce infrastructure, or by integrating load management of the electricity grid with charging of large electric vehicle fleets. This talk will give an overview on how OR can contribute to solve these new challenges in the transportation sector. Examples on projects will be given, current challenges will be discussed, and requirements for OR models will be derived. Some of the models and applications will be discussed in more detail, and insights on how these approaches can be implemented in practice will be given.

### ■ TC-03

*Thursday, 13:30-14:15 - Hörsaal 2*

### Semi-Plenary Correia

Stream: Semi-Plenaries

Chair: *Tobias Harks*

#### 1 - Dynamic pricing with forward-looking consumers

*José Correia*

Determining effective pricing policy when selling to strategic consumers that arrive over time is a growing area that is posing challenging questions with practical implications. In this talk we study a basic pricing problem in which a single unit is on sale and consumers are forward looking. We first discuss a model in which the price can only change at discrete times. Then, we derive optimal pricing schemes for the case in which the price can change continuously. All these pricing schemes require that the seller has commitment power. This is an important assumption that we discuss in detail.

### ■ TC-04

*Thursday, 13:30-14:15 - Hörsaal 3*

### Semi-Plenary Hurink

Stream: Semi-Plenaries

Chair: *Guido Voigt*

#### 1 - Decentralized Energy Management: New Challenges for Operations Research

*Johann Hurink*

Our energy systems undergo a fundamental change. Where in the past the energy mainly was generated in large power plants using fossil fuels, in the future a large part of the generation will result from small plants in decentralized locations using uncontrollable renewable



sources. This leads to a loss of control over a larger fraction of the generation. To be able to compensate for this loss in flexibility on the generation side, we have to create and use flexibility on the consumption side. This has led to the concept of 'Smart Grids' and 'Decentralized Energy Management' is seen as a key element for these Smart Grids. In this talk we first give an overview of the relevant developments in the Energy Supply Chain. Based on the changes we sketch possible concepts and methods for future control of these supply chains. Hereby Decentralized Energy Management is seen as one of the key elements. In a second part, we argue that devices with inherent storage offer large portions of flexibility and discuss a range of scheduling problems that come up for these devices. For a few of these problems we sketch possible solution approaches.

## ■ TC-06

Thursday, 13:30-14:15 - Hörsaal 5

### Semi-Plenary Spieksma

Stream: Semi-Plenaries

Chair: Dirk Briskorn

#### 1 - Scheduling a soccer league

*Frits Spieksma*

Soccer has become a major business involving many stakeholders, such as teams, police, fans, sponsors, and broadcasting companies. Huge amounts of money are being paid for the broadcasting rights, illustrating the economic value of soccer competitions. It also emphasizes the relevance of finding a good schedule. Each involved party has numerous (possibly conflicting) constraints and wishes, and a schedule that satisfies all constraints and wishes simply doesn't exist. Hence, developing a schedule that is considered fair, and that is acceptable to all parties, is a challenge. We describe our experience in scheduling the ProLeague, Belgium's highest professional league, over the last seasons. We outline some of the different models we used, and we emphasize the advantages of using model-based schedules: transparency, perceived fairness, or simply said: the quality of the schedule.

## Thursday, 14:45-16:15

### ■ TD-02

Thursday, 14:45-16:15 - Hörsaal 1

#### Advances in Mixed Integer Programming (i)

Stream: Discrete and Integer Optimization

Chair: Sven Wiese

#### 1 - SCIP-Jack: A Solver for the Steiner Tree Problem and Variants

*Daniel Rehfeldt*

Spawned by practical applications, numerous variations of the classical Steiner tree problem in graphs have been studied during the last decades. Despite the strong relationship between the different variants, solution approaches employed so far have been prevalently problem-specific. In contrast, we pursue a general-purpose strategy that is based on new graph transformations and a branch-and-cut framework. This approach results in a solver able to solve both the classical Steiner tree problem and ten of its variants without modification. These variants include well-known problems such as the prize-collecting Steiner tree problem, the maximum-weight connected subgraph problem, or the rectilinear minimum Steiner tree problem. Bolstered by a variety of new methods, most notably reduction techniques, our solver is not only of unprecedented versatility, but furthermore competitive or even superior to specialized state-of-the-art programs for several Steiner problem variants.

#### 2 - Experiments with conflict analysis in SCIP

*Jakob Witzig, Timo Berthold, Stefan Heinz*

Conflict analysis plays an import role in solving Mixed-Integer Programs (MIPs) and is implemented in most major MIP solvers. The analysis of infeasible nodes has its origin in solving satisfiability problems (SAT). SAT solvers use the concept of aging to drop conflicts that do not frequently yield variable fixings. The age of a conflict approximates the distance between the current node and the node at which the conflict was generated, assuming a depth-first-search node selection. In contrast to SAT solvers, modern MIP solvers frequently "jump" within the tree. Thus, the concept of aging is often not strong enough to control the set of active conflicts, especially, if a variety of conflicts is generated. In this talk, we introduce the idea of a dynamic pool to manage conflict constraints. We present computational experiments conducted within the non-commercial MIP solver SCIP.

#### 3 - MILP experiments with wide split cuts

*Sven Wiese, Andrea Lodi, Andrea Tramontani, Pierre Bonami, Felipe Serrano*

In the classical theory for split cuts, the 'width' of a split set is always equal to one. We investigate cutting planes that arise when widening the associated disjunctions. This allows, e.g., to model non-contiguous domains of (integer) variables (or, stated differently, 'holes' in the domains). The validity of the disjunctions in a MILP can come from either primal or dual information, and we present examples and computational results in both cases. We further explore an exact MILP approach based on these cutting planes, that in addition tackles non-contiguity directly via branching and as a side-effect reduces the model size.

### ■ TD-03

Thursday, 14:45-16:15 - Hörsaal 2

#### Sustainable Resource Management

Stream: CANCELED

## ■ TD-04

Thursday, 14:45-16:15 - Hörsaal 3

### Investment planning and portfolios in energy markets

Stream: Energy and Environment

Chair: *Michael Zipf*

#### 1 - Turning Brown into Green Electricity: Economic Feasibility of Pumped Storage Hydro Power Plants in Open Pit Mines

*Reinhard Madlener, Michael Wessel, Christoph Hilgers*

In the course of the German "Energiewende" a radical shift from fossil and nuclear to renewable power production is underway. However, with increasing shares of intermittent generation from wind and photovoltaic power, maintaining security of supply becomes a challenge, making the extension of the electric grid and bulk storage capacity necessary. The most efficient storage technology is pumped storage hydro (PSH), which allows to generate revenues on the spot market by buying (selling) electricity in off-peak (peak) hours, or on the balancing market by offering positive or negative reserve capacity. Natural sites for PSH power plants are scarce, and likely to encounter substantial public resistance. Abandoned open pit mines are thus interesting candidate locations that may not face as much public resistance as green-field projects. In our study we investigate the investment decision concerning two variants of PSH power technology erected in an open pit mine: In Variant 1, the pit lake forms the lower basin, and the higher basin is built on the mine dump. In Variant 2, the lower basin is established as a tank under the pit lake which is used as the higher basin. In the model-based analysis, we apply the NPV method, sensitivity analysis, and Monte Carlo simulation (to account for electricity price uncertainty). Variant 1 shows that a PSH plant can be constructed at reasonable costs and operated at low unit production costs. However, the investment has to be made before flooding the pit lake, which may take up to 20 years, and render profitability rather unlikely, especially in light of further adverse environmental impacts that may imply additional cost. In contrast, underground storage in the form of tanks (Variant 2) is found to be non-economical.

#### 2 - A Mathematical Programming-Based Approach for an Energy Investment Planning of a Private Company

*Semra Agrali, Fulya Terzi, Ethem Canakoglu, Neslihan Yilmaz*

We consider a private electricity generating company that plans to enter the market that is partially regulated. There is a cap and trade system in operation in the industry. There are nine possible power plant types that the company considers to invest on through a planning horizon. Some of these plants may include a carbon capture and sequestration technology. We develop a mixed-integer linear program for this problem where the objective is to maximize the expected net present value of the profit obtained. We include restrictions on the maximum and minimum possible amount of investment for every type of investment option. We also enforce market share conditions such that the percentage of the total investments of the company over the total installed capacity of the country stay between upper and lower bounds. Moreover, in order to distribute the investment risk, the percentage of each type of power plant investment is restricted by some upper bound. We tested the model for a hypothetical company operating in Turkey. The results show that the model is suitable to be used for determining the investment strategy of the company.

#### 3 - Optimising the natural gas supply portfolio of a gas-fired power producer

*Nadine Kumbartzky*

The expansion of gas-fired power plants has led to increasing interactions between the natural gas and electricity market. In order to effectively manage risk of volatile energy prices, operators of gas-fired power plants need to take natural gas procurement and power plant resource planning simultaneously into account. An industrial company is considered that owns a gas-fired combined heat and power (CHP) plant. To ensure a stable heat and power supply, the amount of gas needed to operate the CHP plant must be available at any time. Natural gas can be procured by signing supply contracts or by engaging in the natural gas spot market. A two-stage stochastic MILP is proposed that optimises the gas supply portfolio and the CHP plant operation according to revenue potential in the electricity spot market. Uncertainty of gas and electricity spot prices is appropriately addressed by

means of stochastic processes. Price risk is explicitly taken into account by the Conditional Value-at-Risk (CVaR). A convex combination of expected total costs and CVaR allows for representing different risk preferences of the decision maker. The efficient performance of the presented approach is illustrated in a case study using the example of German energy markets. The results reveal the significant influence of different risk preferences on the optimal gas supply portfolio composition as well as on CHP plant operation.

## ■ TD-05

Thursday, 14:45-16:15 - Hörsaal 4

### Sequential Scheduling Games (i)

Stream: Game Theory and Experimental Economics

Chair: *Matús Mihalák*

#### 1 - The Price of Anarchy for Set Packing Games

*Marc Uetz, Jasper de Jong*

The talk addresses set packing games where each of  $n$  players selects a subset of items with corresponding values to maximize the total value of the selected items. Players are restricted in their choice of items by downward-closed feasibility constraints, and each item can only be chosen by a single player. The problem is motivated by scheduling problems to maximize throughput. When each player is able to choose an  $\alpha$ -approximate solution, we show that the price of anarchy is equal to  $(\alpha+1)$ . We improve upon this result in two directions. First, when players make sequential decisions and we consider subgame perfect equilibria instead of Nash equilibria, we show that the price of anarchy drops to about  $(\alpha+1/2)$ . Second, when coalitions of  $k$  players are allowed to cooperate and use an arbitrary profit sharing protocol, we give a parametric result and show that the price of anarchy equals  $(\alpha+(n-k)/(n-1))$ .

#### 2 - Tighter Bounds on the Inefficiency Ratio of Stable Equilibria in Load Balancing Games

*Paolo Penna, Akaki Mamageishvili*

In this paper we study the inefficiency ratio of stable equilibria in load balancing games introduced by Asadpour and Saberi (WINE 2009). We prove tighter lower and upper bounds of  $7/6$  and  $4/3$ , respectively. This improves over the best known bounds for the problem ( $19/18$  and  $3/2$ , respectively). Equivalently, the results apply to the question of how well the optimum for the  $\$L_2\$$ -norm can approximate the  $\$L_{\infty}\$$ -norm (makespan) in identical machines scheduling.

#### 3 - Sequential solutions in machine scheduling

*Akaki Mamageishvili, Paul Duetting, Matús Mihalák, Paolo Penna*

We study the sequential machine scheduling problem. In this setting players join the game one by one and make decisions based on previous and/or future moves of other players. We are interested in the ratio between the makespan of the solution and the social optimum. First we show matching lower bounds for identical machine scheduling. In particular  $2-1/m$  lower bound for the sequential price of anarchy and  $4/3 - 1/(3m)$  lower bound for the permutation with decreasing weights. These lower bounds are matching to upper bounds proved by Hassin and Yovel. Next we show that there is always a permutation which gives optimum solution if players act greedily and each player chooses the least loaded machine. To the end we consider unrelated machines and show that for 2 machines there is an adaptive order of players which results into the optimum solution, while for already 3 machines there is no such ordering.

## ■ TD-06

Thursday, 14:45-16:15 - Hörsaal 5

### Revenue Management for Urban Transportation

Stream: Pricing and Revenue Management

Chair: *Michael H. Breitner*

**1 - Revenue Management meets Carsharing: Optimizing the Daily Business**

*Justine Broihan, Max Möller, Kathrin Kühne, Marc-Oliver Sonneberg, Michael H. Breitner*

Carsharing is a transportation alternative that enables flexible use of a vehicle instead of owning it by paying trip-dependent fees. In recent years, this service denotes a considerable increase of new providers, which face an exponentially growing number of customers worldwide. As a consequence, rising vehicle utilization leads providers to contemplate revenue management elements. When focusing on station-based carsharing concepts, these are typically based on advance reservations. This makes them perfectly suitable for the application of demand-side management approaches. Demand-side management allows providers to optimize their revenues by accepting or rejecting certain trips. We respectively develop an optimization model for revenue management support. Based on an existing model of the hotel business, special consideration is drawn to carsharing related features. For instance, the implementation of a heterogeneously powered fleet allows providers to choose a certain limit of emissions to fulfill local requirements. We implement the mathematical model into the modeling environment GAMS using the solver Couenne. Conducted benchmarks show sensitivities under the variation of different input values, for example risk tolerances. In contrast to the often used first-come first-serve-principle, the results indicate the usefulness of the developed model in optimizing revenues of today's carsharing providers.

**2 - Revenue management approach for electric vehicles in two-way carsharing systems**

*Isa von Hoesslin, Kerstin Schmidt, Thomas Volling, Thomas Spengler*

In two-way e-carsharing systems an allocation of customer requests to electric vehicles with the "first come, first served" principle currently used in industry leads to an inefficient usage of electric vehicles and a loss of revenues. Therefore e-carsharing operators need a decision support system for the efficient acceptance of customer requests. Special challenges arise from the limited and perishable capacity of the electric vehicle in combination with a second limited and perishable but also storable capacity with dynamic replenishment - the battery capacity of the electric vehicle with the corresponding charging process. For each incoming customer request, the e-carsharing operator has to decide whether to accept the request in consideration of intertemporal interdependencies that arise between the requests due to different user profiles depending on start and length of booking as well as starting station. To address these characteristics, we present a revenue management approach using a randomized version of certainty equivalent control. The performance of the proposed approach in comparison to a "first come, first served" approach and an ex-post optimal solution is illustrated in a simulation study.

**3 - E-Fulfillment for Attended Last-Mile Delivery Services in Metropolitan Areas**

*Magdalena Lang, Catherine Cleophas, Jan Fabian Ehmke, Charlotte Köhler*

With two-digit growth rates predicted for e-commerce revenues, cost efficient, customer-oriented, and sustainable delivery services gain importance. This contribution focuses on planning attended last-mile delivery services, i.e., the final leg of the supply chain. As the customer has to be present for deliveries of for example groceries, a service time window has to be agreed upon already when the order is accepted. Thus, we consider service time windows as a scarce resource and as the critical interface between order capture and order delivery. To optimally utilize this scarce resource, we propose combining concepts of revenue management and vehicle routing to extend tactical and operational planning for e-fulfillment. This presentation will focus particularly on opportunities for forecasting customer requests and customer characteristics and related requirements for data availability, and forecast quality. We will present first results and provide an outlook on ongoing research.

**■ TD-07**

*Thursday, 14:45-16:15 - Hörsaal 6*

**Gas Network Optimization (i)**

Stream: Graphs and Networks

Chair: *Claudia Gotzes*

**1 - Capacity management in gas networks**

*Claudia Gotzes*

The focus on the use and the transportation of natural gasoline is getting stronger and stronger while trying to reduce energy production coming from coal and crude oil. Not only the gas for heating in households, but also to supply the industry with power is very important. On the other side, due to the liberalization of the gas market in Europe, it is getting more and more difficult for the transportation companies to calculate the use of exit and entry points by the customers. In this talk we will not only focus on the non-deterministic customer behavior, but also on the modeling of the gas physics that determine the gas flow through the network.

**2 - Two-stage Stochastic Semidefinite Programming and Application to AC Power Flow under Uncertainty**

*Tobias Wollenberg, Rüdiger Schultz*

We consider risk neutral and risk averse two-stage stochastic semidefinite programs with continuous and mixed-integer recourse, respectively. For these stochastic optimization problems we analyze their structure, derive solution methods relying on decomposition, and apply our results to unit commitment in alternating current (AC) power systems.

**3 - Analysis of operation modes in gas compressor stations**

*Tom Walther, Benjamin Hiller, René Saitenmacher*

We consider operation modes of compressor stations in gas networks, which are used to control the global gas flow in the network. Following the modelling in [1], each compressor station is represented by a single subnetwork that is suited to model all possible operation modes for it, but in return contains redundancy. Our main goal is to obtain non-redundant models for the operation modes in order to improve the performance of MIPs that use these models. In particular, we determine the feasibility of an operation mode and detect redundancy between different operation modes. We also obtain simplified network models in this process.

Operation modes for compressor stations are given as decisions which are joint specifications of switching states for all valves and compressors in a station. We represent a decision by the flow network that is described by it. To determine whether a decision admits a physically feasible flow/pressure combination, we employ bound tightening. We developed a fast, approximate method based on propagation and an exact optimization based method at reasonable computational cost.

In terms of redundancy detection, we face the problem that decisions' networks are difficult to compare as they usually contain complex redundant structures. We developed a network reduction process allowing us to simplify decisions' networks such that they can then be more effectively tested for isomorphisms between them. As a side-product, we obtain equivalent, but simplified network models.

We provide extensive test results that demonstrate the success of our approach.

[1] Koch et al: Evaluating Gas Network Capacities. SIAM, MOS-SIAM Series on Optimization, 2015.

**■ TD-08**

*Thursday, 14:45-16:15 - Seminarraum 101/103*

**Emission Oriented Transportation Planning (i)**

Stream: Logistics, Routing and Location Planning

Chair: *Frank Meisel*

Chair: *Thomas Kirschstein*

**1 - Comparing the minimization of travel times, emissions and costs in urban routing**

*Jan Fabian Ehmke, Ann Campbell, Barrett Thomas*

Minimization of emissions has become an important issue for logistics companies operating in urban areas. We model emissions based on the Comprehensive Emissions Model (CEM), which derives emissions from speed, load, and engine type. Based on the CEM, we plan routes for a combined cost objective consisting of fuel and driver costs. The CEM is embedded within a tabu-search heuristic that was originally developed for the time-dependent vehicle routing problem. The procedure is adapted to include the computation of time-dependent, expected emissions- and cost-minimized paths between each pair of customers on the route. For computational experiments, we use instances derived from a real road network dataset and 230 million speed observations. We compare the emissions- and cost-optimal routes with solutions arising from more traditional objectives, e.g. minimizing distances and travel times, to understand how the planned routes differ. We then analyze how routes change with different fleet compositions, where emissions and cost objectives can lead to quite different results than traditional objectives.

## 2 - An emission-minimizing vehicle routing problem with heterogeneous vehicles and pathway selection

*Thomas Kirschstein, Martin Behnke, Christian Bierwirth*

In addition to cost- and time-orientation, greenhouse gas emission has become a further command variable for planning processes in the transportation industry. A lot of scientific literature is devoted to the development of planning approaches taking into account the emissions of transport processes. In order to minimize a transport process' emissions, a lot of factors affecting the emissions have been studied. Besides the total distance covered by a transport process, the modal split, payload, travelling speed as well as vehicle type are identified as most influential planning parameters. In this talk, we formulate an emission-minimizing vehicle routing problem with heterogeneous vehicles and pathway selection (EVRP-VC-PS). The model seeks to find a set of tours such that total emission quantity of all vehicles employed is minimized, all customers are served, and the vehicles' capacity restrictions are met. We use an emission model taking into account vehicle specific characteristics, payload, speed as well as traffic conditions as parameters. In the model, we assume a problem setting often met in city logistics systems. For travelling between customers among two pathways can be chosen. First option is the direct path (through the city) using urban roads with low average speed and frequent acceleration processes. Alternatively, a city highway can be used resulting in a detour (compared to the direct path) but higher average speed and less acceleration processes. Experiments with artificial data sets illustrate the pathway selection effect on total emissions comparing classic distance-minimizing and emission-minimizing tours.

## 3 - Vehicle Re-Use for Fuel Minimization by Solving the Capacitated Vehicle Routing Problem with Different Vehicle Classes

*Jörn Schönberger*

The capacitated vehicle routing problem with different vehicle classes has been proposed in the context of the fleet fuel consumption minimization. Here, light vehicles (like limousines, minibuses or vans) are dispatched simultaneously with heavy vehicles (like trucks and/or truck/trailer compositions). Instead of using a heavy truck to carry only a light payload the usage of a light vehicle can lead to reduced fleet fuel consumption since the movement of the dead weight of a light vehicle requires less fuel than the movement of the dead weight of a heavy truck. Since the payload capacity of a light vehicle is low and since the marginal fuel consumption induced by each additional payload ton is large (compared to a heavy vehicle) the length of a route assigned to a light vehicle is relatively short compared to the distance of the route assigned to a heavy vehicle. Therefore, a light vehicle can process two or even more round trips starting and ending in the depot while a heavy vehicle is still processing its only route. The re-use of the small vehicle helps to keep the number of vehicles in the fleet small. A mathematical model for this problem is proposed and initial computational experiments are reported.

## ■ TD-09

*Thursday, 14:45-16:15 - Seminarraum 105*

### Solver Approaches

Stream: Software and Modelling Systems

Chair: *Andrea Cassioli*

## 1 - Solving routing and scheduling problems using LocalSolver

*Frédéric Gardi, Thierry Benoist, Julien Darlay, Bertrand Estellon, Romain Megel, Clément Pajean*

In this talk, we introduce LocalSolver, a heuristic solver for large-scale optimization problems. It provides good solutions in short running times for problems described in their mathematical form without any particular structure. Models supported by LocalSolver involve linear and nonlinear objectives and constraints including algebraic and logical expressions, in continuous and discrete variables. LocalSolver starts from a possibly infeasible solution and iteratively improves it by exploring some neighborhoods. A differentiator with classical solvers is the integration of small-neighborhood moves whose incremental evaluation is fast, allowing exploring millions of feasible solutions in minutes on some problems.

We will present the set-based modeling formalism recently introduced in LocalSolver. Offering set decisions (sets/lists of integers) and operators (count, at, indexOf, contains, disjoint, partition), this mathematical formalism allows to model routing and scheduling problems naturally and compactly, as well as to solve them more efficiently than the traditional Boolean modeling approach related to mixed-integer linear programming. We will show application examples on basic combinatorial problems (traveling salesman, vehicle routing, flowshop scheduling) together with performance benchmarks.

## 2 - The MOSEK Fusion API: a simple and safe framework for conic optimization

*Andrea Cassioli*

Conic optimization is a mainstream tool nowadays, and so dedicated tools are taking the stage and improve their functionalities and user-friendliness. MOSEK provides a dedicated API for conic optimization, the Fusion API. It provides an object-oriented framework for conic optimization with emphasis on safety, readability and portability. The new MOSEK 8 release contains substantial improvements of the Fusion API: a new C++11 interface, more operators, support for Python3 and Pypy, pretty printing and an overall simplification of the API. During this talk we will walk through the Fusion general design and new features, as well as discuss common pit-falls and tricks.

## 3 - On the Role of Optimization Modeling in the Algorithm Economy

*Ovidiu Listes*

Based on our experiences in applying Analytics and Optimization using AIMMS, we describe concrete aspects of the role the optimization modeling can already play in the new algorithmic business. Such aspects include: starting with a model addressing a decisional problem, moving on to full app development, deploying apps in enterprise wide systems with client-server architectures and user-friendly, local or web-based interfaces, and further on performing these actions in the cloud as the platform of the digital organization. For such aspects we provide illustrative AIMMS-based solution examples. By this, we support the idea that algorithms define action and therefore, the companies are not just valued based on their big data, but on the algorithms which turn the data into action and impact customers.

## ■ TD-10

*Thursday, 14:45-16:15 - Seminarraum 108*

### Sourcing and Capacity Management in Uncertain Environments

Stream: Optimization under Uncertainty

Chair: *Gerd J. Hahn*

#### 1 - The Value of Capacity Flexibility in Economic Crises

*Gerd J. Hahn, Achim Koberstein, Semën Nikolajewski, Sven Woigt*

Automotive suppliers are concerned with the flexibility of their production networks and aim for robust mid-term plans in order to cope with persisting economic instability. This instability could involve the risk of a new demand slump as seen during the financial crisis. In this presentation, we investigate the issues of managing flexibility and implementing robust planning approaches while considering the specific requirements of automotive suppliers in a disruptive demand environment. Our contribution is twofold: first, we develop a robust optimization approach for strategic-tactical supply chain planning and provide

a procedure for demand modeling in such a setting. For this purpose, we rely on Conditional Value-at-Risk (CVaR) as a prevalent risk measure. Second, the value and inter-dependencies of process and volume flexibility are analyzed for supplier production networks which are related to product (re-)allocation and capacity balancing decisions. An extensive numerical study is used to evaluate the approach and to derive managerial insights based on a real-life case example from the industry.

## 2 - Optimal replenishment under price uncertainty

*Esther Mohr*

We aim to find optimal replenishment decisions without having the entire price information available at the outset. Although it exists, the underlying price distribution is neither known nor given as part of the input. Under the competitive ratio optimality criterion, we design and analyze online algorithms for two related problems. Besides the reservation price based decision how much to buy we additionally consider the optimal scheduling of orders. We suggest an online algorithm that decides how much to buy at the optimal point in time. Results show that the problem of finding a replenishment strategy with best possible worst-case performance guarantees can be considered as an extension of the online time series search problem.

## 3 - Stochastic optimization of modular production networks considering demand uncertainties

*Tristan Becker, Pascal Lutter, Stefan Lier, Brigitte Werners*

In the process industry markets are facing new challenges. While product life cycles are becoming shorter, the differentiation of products grows. This leads to uncertain product demands in time and location. In contrast to large commodity markets, where a vast amount of orders compensates variation in demand, this does not apply for niche markets. Due to low production flexibility and long time to markets, large-scale conventional plants are not well suited for production in these highly volatile markets. The focus of research therefore shifts to modular production units, which can be installed in standardized transportation iso-containers. Using modular units, the supply chain design is becoming more flexible, as production locations can be located in direct proximity to resources or customers. In answer to short-term demand changes, modifications to capacity can be made by numbering-up containers. Utilizing modular production units, the structure of the production network requests dynamic adaptations in each period. Subsequently, once the customer demand realizes, an optimal match between available production capacities and customer orders has to be determined. This decision situation imposes new challenges on planning tools, since frequent adjustments of the network configuration have to be computed for a large amount of specialty products based on uncertain demand. To cope with uncertainty we develop different mathematical models. We present stochastic and robust mixed-integer programming formulations to hedge against demand uncertainty. In a computational study the novel formulations are compared and evaluated based on large real-world data sets in terms of runtime and solution quality.

that the determined RTS-value is - from a decision-maker's point of view - unrealistically high (or low) and thus impracticable. Therefore, a new approach to treat this issue will be presented. In a nutshell: We identify a new kind of mavericks - we call them RTS-mavericks; and in order to cope with this problem, we propose a median-based outlier test that leads to a new type of constraints in DEA - named scale restrictions.

## 2 - Regionalized Assortment Planning for Multiple Chain Stores

*Michael Hopf, Benedikt Kasper, Clemens Thielen, Hans Corsten*

In retail, assortment planning refers to selecting a subset of products to offer that maximizes profit. Assortments can be planned for a single store or a retailer with multiple chain stores where demand varies between stores. In this paper, we assume that a retailer with a multitude of stores wants to specify her offered assortment. To suit all local preferences, regionalization and store-level assortment optimization are widely used in practice and lead to competitive advantages. When selecting regionalized assortments, a tradeoff between expensive, customized assortments in every store and inexpensive, identical assortments in all stores that neglect demand variation is preferable.

We formulate a stylized model for the regionalized assortment planning problem (APP) with capacity constraints and given demand. In our approach, a 'common assortment' that is supplemented by regionalized products is selected. While products in the common assortment are offered in all stores, products in the local assortments are customized and vary from store to store.

Concerning the computational complexity, we show that the APP is strongly NP-complete. The core of this hardness result lies in the selection of the common assortment. We formulate the APP as an integer program and provide algorithms and methods for obtaining approximate solutions and solving large-scale instances.

Lastly, we perform computational experiments to analyze the benefits of regionalized assortment planning depending on the variation in customer demands between stores.

## 3 - Application of Ant Colony Optimization in Solving Facility Layout Problem of an Elevator Automatic Door Production Plant

*Tuba Ulusoy, Mehmet Aktan*

Facility layout design studies aim to reach different qualitative and quantitative objectives. Minimizing material handling cost is the most considered and common objective and it can be achieved by an effective facility layout design. In this study, an attempt is made to solve facility layout problem (FLP) of an elevator automatic door production plant which is located in Konya, Turkey and it is aimed to find a layout design that has minimum material handling cost. Material handling cost is equal to 80259,43 in current layout. Wooden pallets that are transported by hydraulic transpalets are used for material handling in the plant. These transpalets are moved between departments by man power. It is known that each component of elevator automatic door has different size, so handling of big components is not as easy as small ones. For this reason, size of components is considered as a cost of material flow from department  $i$  to department  $j$  and it is added to the objective function by multiplying with distance and flow between departments in the plant. The FLP was formulated as a Quadratic Assignment Problem (QAP) and it was linearized. Linearized model was run by GAMS and a feasible solution could not be found. To find a solution for this FLP, Ant colony optimization (ACO) that usually gives good solutions for QAP was decided to use. Taguchi experimental design technique was applied by Minitab to find the best combination of ACO's parameters that can help to find an objective function value which is close to optimal. 25 different combinations of parameters were generated by Taguchi experimental design with 6 factors and 5 levels. These parameter levels were run in ACO algorithm which is coded in Matlab. Material handling cost is equal to 54487 in proposed layout which is found by using ACO.

## ■ TD-11

*Thursday, 14:45-16:15 - Seminarraum 110*

### Advances Production and Operations Management

Stream: Production and Operations Management

Chair: *Clemens Thielen*

#### 1 - RTS-Mavericks in DEA

*Andreas Dellnitz*

(In-)Efficiency scores of ex-post production activities are generally measured relative to an estimated production frontier. Data Envelopment Analysis (DEA) is a well-established non-parametric method to get such information for the activities of some comparable Decision-Making-Units (DMUs). It is well-known that this technique can be applied under the assumption of constant returns to scale (CRS) or variable returns to scale (VRS), respectively. In fact, if it is done under CRS, the returns to scale (RTS) for each activity equals one. More precisely: an input change results in an equiproportional change of outputs. However, in case of variable returns to scale the situation might be different; now the respective input variation can lead to a proportionally less or even higher output change. But often it becomes clear

## ■ TD-12

*Thursday, 14:45-16:15 - Seminarraum 202*

### Real-World Applications

Stream: Metaheuristics

Chair: *Lars-Peter Lauen*

**1 - Alternative fitness functions in the development of models for prediction of patient recruitment in multi-centre clinical trials**

*Gilyana Borlikova, Michael Phillips, Louis Smith, Michael O'Neill*

For a drug to be approved for human use, its safety and efficacy need to be evidenced through clinical trials. At present, patient recruitment is a major bottleneck in conducting clinical trials. Pharma and contract research organisations (CRO) industries are actively looking into optimisation of different aspects of patient recruitment. One of the avenues to approach this business problem is to improve the quality of selection of investigators/sites at the start of a trial. This study builds upon previous work that used Grammatical Evolution (GE) to evolve classification models to predict the future patient enrolment performance of investigators/sites considered for a trial. Selection of investigators/sites, depending on the business context, could benefit from the use of either especially conservative or more liberal predictive models. To address this business need, decision-tree type classifiers were evolved utilising different fitness functions to drive GE. The functions compared were classical accuracy, balanced accuracy and f-measure with different values of parameter beta. The issue of models' generalisability was addressed by introduction of a validation procedure. The predictive power of the resultant GE-evolved models on the test set was compared with performance of a range of machine learning algorithms widely used for classification. The results of the study demonstrate that flexibility of GE induced classification models can be used to address business needs in the area of patient recruitment in clinical trials.

**2 - Integrated Biorefinery Planning using a Nested Evolutionary Strategy**

*Tim Schröder, Lars-Peter Lauven, Jutta Geldermann*

Biorefinery concepts provide a manifold product portfolio capable of fulfilling many needs of modern societies from biomass. The profitability, and thus the practical realization of such biorefineries, heavily depends on the availability of the spatially distributed biomass inputs, which in turn influences the optimal location, capacity, and setup of potential biorefineries. We present an integrated approach for simultaneously planning a Fischer-Tropsch biorefinery's location, capacity, and configuration in a continuous solution space while. Detailed consideration of the spatial availability yields a noisy objective function. While such noisy objective functions can generally be solved using metaheuristics, the problem at hand does not converge reliably when solved with an Evolutionary Strategy (ES) algorithm due to strict constraints and interferences between variable dimensions. In order to tackle this problem, a nonlinear program (NLP) is nested inside an ES algorithm. Through repeated de- and recomposition, the integrated problem can be solved handling the noise inducing variables in the ES and optimizing the remaining smooth variables in the exact NLP.

**3 - Branch-and-cut for forest harvest scheduling problems subject to clearcut and core area constraints**

*Isabel Martins, Miguel Constantino*

Integrating forest fragmentation into forest harvest scheduling problems adds substantial complexity to the models and solution techniques. Forest fragmentation leads to shrinking of the core habitat area and to weakening of the inter-habitat connections. In this work, we study forest harvest scheduling problems with constraints on the clearcut area and constraints on the core area. We propose a mixed integer programming formulation where constraints on the clearcut area are the so-called cover constraints while constraints on the core area are new in the literature as far as we know. As the number of constraints can be exponentially large, the model is solved by branch-and-cut, where the spatial constraints are generated only as necessary or not before they are needed. Branch-and-cut was tested on real and hypothetical forest data sets ranging from 45 to 1363 stands and temporal horizons ranging from three to seven periods were employed. Results show that the solutions obtained by the proposed approach are within or slightly above 1% of the optimal solution within three hours at the most.

**1 - MetaSimLab: A laboratory for validating and calibrating agent-based simulations for business analytics**

*Janina Knepper, Catherine Cleophas*

Simulations are frequently used to develop and evaluate new and improved approaches for business analytics and decision support. Whenever the result depends on the interaction between independent actors, agent-based simulation models are the tools of choice. Examples are the interaction of supplier and customer in automated revenue management or the interactions of analysts with decision support systems. To be reliable, agent-based simulations have to be empirically calibrated and validated. After calibration determines input parameters, validation measures the deviation between simulation results and empirical observations. Existing calibration approaches are rarely automated; manual calibration is costly in terms of time and effort. Therefore, new calibration methods and a tool for their evaluation are needed. This contribution introduces the laboratory environment MetaSimLab, which is designed to evaluate the efficiency and effectiveness of alternative calibration approaches. It is capable of comparing calibration approaches given exchangeable simulation models, validation approaches, and empirical data sets. We present both a numerical example to illustrate the MetaSimLab's functionality, a perspective on novel calibration methods, and an outlook on further research.

**2 - Trajectory Optimization under Kinematical Constraints for Moving Target Search**

*Manon Raap*

Various recent events in the Mediterranean sea have shown the enormous importance of maritime search-and-rescue missions. By reducing the time to find floating victims, the number of casualties can be reduced. A major improvement can be achieved by employing unmanned aerial systems for autonomous search missions. In this context, the need for efficient search trajectory planning methods arises. Existing approaches either consider K-step-lookahead optimization without accounting for kinematics of fixed-wing platforms or propose a suboptimal myopic method. A few approaches consider both aspects, however only applicable to stationary target search. We present a novel method for Markovian target search-trajectory optimization. This is a unified method for fixed-wing and rotary-wing platforms, taking kinematical constraints into account. It can be classified as K-steplookahead planning method, which allows for anticipation to the estimated future position and motion of the target. The method consists of a mixed integer linear program that optimizes the cumulative probability of detection. We show the applicability and effectiveness in computational experiments for three types of moving targets: diffusing, conditionally deterministic, and Markovian. This approach is the first K-step-lookahead method for Markovian target search under kinematical constraints.

**3 - Scheduling of a Partially Automated Production**

*Frank Herrmann*

In recent years, a considerable amount of interest has arisen for scheduling problems with technological restrictions. For example, no-buffer flow-shop scheduling problem are well investigated. Here a real world flow shop with a transportation restriction is regarded. It has to produce small batches, very often with a lot size of one, with short response times. Thus, scheduling algorithms are needed to ensure that under the constraint of a high average load of the flow shop, the due dates of the production orders are met. This transportation restriction reduces the set of feasible schedules even more than the no-buffer restrictions discussed in the literature in the case of limited storage. Still this problem is NP-hard. Due to the transportation restriction, the duration of a job A on the flow-shop depends on the other jobs processed on the flow-shop in the same timeframe which is called a cycle. Realistic processing times are achieved by a simulation of the scheduling of A which includes the next jobs until A has left the flow-shop. The usage of such realistic processing times instead of net processing times improves the priority rules by around 16%. There are pools of jobs where a large variance of the cycle times is beneficial and pools of jobs where a small variance is better. This is partially detected by a genetic algorithm. This improves the performance by another 34%.

■ **TD-13**

Thursday, 14:45-16:15 - Seminarraum 204

**Simulation Models II**

Stream: Simulation and Stochastic Modeling

Chair: *Frank Herrmann*

■ **TD-14**

Thursday, 14:45-16:15 - Seminarraum 206

**Rankings, Goals and (Integer) Linear Programming**

Stream: Decision Theory and Multiple Criteria Decision

## Making

Chair: *M. Karimi-Nasab***1 - The minimal angle jump technique for the simplex method***Monsicha Tipawanna, Krung Sinapiromsaran*

In this paper, we present the minimal angle jump for the simplex method. The essence of this method is to move from an initial basic feasible solution to another basic feasible solution, corresponding to the lowest angle between normal vector of linear constraints and gradient of the objective function. If the new current basic feasible solution is not optimal then the simplex method with Dantzig's pivot rule is applied until the optimal solution is obtained. We can illustrate by examples that our method improves the simplex method by the number of iterations for solving linear programming problems.

**2 - Multi-objective formulation of a multi-attribute decision making problem***M. Karimi-Nasab*

In a multi-attribute decision making problem, we are given  $m$  alternatives,  $A(1), \dots, A(m)$ , each scored by  $k$  different criteria,  $C(1), \dots, C(k)$ . In other words,  $S(i,j)$  denotes the score of alternative  $A(i)$  by criterion  $C(j)$ . Also, we can divide the criteria into two subsets: pleasant criteria and unpleasant criteria. A pleasant criteria is the one that a rational decision maker is expected to be happier if we have alternatives of higher scores in that criterion. And similarly, an unpleasant criterion is the one that a rational decision maker is expected to be happier if we have alternatives of smaller scores in that criterion. For example, if the decision maker wants to decide which automobile to buy among a set of automobiles in the market, one criterion would be the "price" and naturally it is an unpleasant criterion because the decision maker would become happier if he/she is asked to pay less. On the other hand, "maximum speed" can be regarded a pleasant criterion. The problem is to determine the best ranking of these alternatives in order to know which alternative should be suggested at the first priority  $A[1]$  to the decision maker, and which alternative should be suggested to him/her at the second priority  $A[2]$  and so forth till determining which alternative should be suggested to him/her at the last priority  $A[m]$ . Further, once we know the ranking of the alternatives, we can just recommend  $A[1]$  to the decision maker. Potentially, there is  $m!$  different rankings, but some of them are superior to the others or dominate the others because the non-dominated rankings are nearer to the desires of the decision maker. Here, every criterion is considered as an objective function and the problem is formulated as a mixed integer multi-objective optimization problem.

**3 - Generalized Imprecise Multi-Choice Goal Programming***Hocine Mouslim, Sakina Melloul*

Herbert A. Simon states that modern managers wish to "satisfice" to reaching goals subject to the optimization of a single objective. In such situations, Multi-Choice Goal Programming (MCGP) model can be used and applied to solve this type of problems. In other words, the technique of MCGP reflects a good approximation of these real world situations. However, in some management problems, it may exist situations that the decision maker could not be interested in presenting his preferred goals in a precise manner. In this paper, an efficient methodology is presented, which is considered as a combination between the (MCGP) model suggested by Chang for standard goal programming (GP), and the technique of fuzzy GP (FGP), where the concept of utility functions (MTFs) is used for modelling the fuzziness and the managers preferences of all kinds of the goals. The model of MCGP is adapted in a very evident to introduce the technique of FGP for solving this type of problems. One of the main advantages of the proposed model is that it provides the decision makers (managers) with more control over their preferences. Finally, an illustrative example demonstrates the effectiveness of our proposed model.

**1 - The Introduction of a New Algorithm to Determine Buffer's Size in Critical Chain with Use of Environmental Indices: A Case Study***Mohammad Khalilzadeh*

In this paper, we introduce a new algorithm to determine buffer sizes in critical chain with environmental indices such as suppliers, contractors and sponsors. In this research, the expert judgment has been used to determine the importance weights of criteria. These criteria have been evaluated by six sub criteria using Analytic Hierarchy Process. As a case study, we collected historical data from the project of Sodium Carbonate production plant. Then, we calculated and compared Feeding Buffers and Project Buffer with different methods. As a result, we showed the proposed method is more reliable and accurate due to the practical indices. Also we demonstrated that the results of this algorithm are between the APD and APRT algorithms which clearly proved the validity of the proposed algorithm.

**2 - Search Algorithms for Improving the Pareto Front in a Timetabling Problem with a Solution Network-based Robustness Measure***Can Akkan, Gulcin Ermis*

We develop search algorithms ((i) local search, and (ii) matheuristic that solves a set of MIP models) for creating and improving a network of solutions for an academic timetabling problem. This network of solutions, in which edges are defined by the Hamming distance between pairs of solutions, is used to calculate a robustness measure. The robustness measure is based on a definition of disruption (the time slot to which an entity had been assigned is no more feasible for that entity) and a predefined heuristic for responding to this disruption (which is, choosing one of the neighbors of the disrupted solution). Taking into account the objective function of the timetabling problem and this robustness measure results in a bi-criteria optimization problem where the goal is to improve the Pareto front. The fact that robustness measure is defined for a set of neighboring solutions differentiates the problem from most bi-criteria scheduling models where both criteria can be measured for a given solution. Furthermore, the matheuristic uses the solution pool feature of CPLEX to essentially use it as the main building block of a search algorithm. These two characteristics make the approach used here applicable to most other combinatorial optimization problems with robustness criterion. We compare the performance of the heuristics on seven semesters' actual data. Results show that highly robust solutions can be found with 3-5 objective vectors on the Pareto front. More generally, in discrete optimization problems such as timetabling, with lots of symmetries that yield a large number of good alternative solutions, simple local search heuristics can be used to identify robust solutions in a reasonable amount of time (supported by TUBITAK Grant 214M661)

**3 - Recoverable robustness in scheduling problems***Han Hoogeveen, Marjan van den Akker, Judith Stoef*

Solving optimization problems is normally done with deterministic data. In practice, however, all kinds of disturbances may occur, which are modeled by distinguishing several discrete scenarios that occur with a given probability. The occurrence of a disturbance may make the planned solution infeasible, and to repair these infeasibilities, we are allowed to update the plan according to a pre-specified, simple recovery algorithm, as soon as we know which disturbances have occurred. A solution then consists of a solution for the undisturbed case that can be made feasible for each scenario by applying a given, simple recovery algorithm. The value of this solution is then equal to the expected value of the realized solution. This restricted type of two-stage stochastic programming is known as recoverable robustness, which originates from railway scheduling.

We apply the concept of recoverable robustness to the problem of minimizing the number of late jobs on one machine where the processing times of the jobs are uncertain. The undisturbed problem can be solved by the algorithm of Moore-Hodgson, and we can update it for a given scenario by applying Moore-Hodgson to the initial solution. Nevertheless, the problem turns out to be NP-hard, even if there is only one scenario. We present a dominance rule, which can be used to identify jobs that will be on-time in the optimum solution. We further consider several enumerative methods, like branch-and-bound, branch-and-price, and dynamic programming.

**TD-15**

Thursday, 14:45-16:15 - Seminarraum 305

**Robust Scheduling**

Stream: Project Management and Scheduling

Chair: *Han Hoogeveen*

## ■ TD-16

Thursday, 14:45-16:15 - Seminarraum 308

### Decision Support and Scheduling

Stream: Project Management and Scheduling

Chair: *Marcus Wiens*

#### 1 - Integrated scheduling approach for future capability development based on genetic algorithm

*Michael Preuß*

Based on continuous future development and the current capability state including strategic objectives and guidelines of the German Federal Ministry of Defense the medium-term planning is a key function to provide proper capabilities in the future. To ensure a continuous, efficient and target-oriented capability management, we developed an integrated approach to meet challenges of the dynamic and complex environment. Regarding all constraints like predecessor relationships, different categories of budgets or fixed projects, there are roughly more than  $8 \times 10^{250}$  different possibilities in setting of 200 projects. The underlying resource-constrained scheduling problem was used to formalize the task definition. We developed a holistic process which determines project priorities deduced from a scenario based capability approach. Subsequently, an adapted genetic algorithm (GA) is used to identify feasible schedules minimizing the makespan subject to resources availabilities and precedence constraints. We analyze the structural similarity of already existing schedules due to the cost trade-off between replanning and the benefits of the optimized solution. With the help of a comprehensive management cockpit, we involve decision makers into the optimization process. In order to provide an appropriate decision support, we visualize the results in an intuitive way.

#### 2 - Endogenous Risks in Project Exploration

*Marcus Wiens, Frank Schultmann*

Project delay and cost overrun are the two main problems in project management with increasing importance for large projects. In interviews, experts frequently mention an insufficient (*ex ante*) project exploration as one of the major causes. The argument runs as follows: As the investment in project exploration is sunk if the planned project is given up there is a tendency towards underinvestment in project exploration. This paper applies an approach from signal detection theory to analyze this argument in detail. It works out the basic mechanisms of this incentive problem for varying assumptions and discusses potential solutions to mitigate this risk.

#### 3 - Risk Analysis in Airport Construction Projects

*Ahmet Gokhan Tiryaki, Burze Yasar, Oncu Hazir*

Considering the fact that the most of the contractors face difficulties and problems while dealing with risks and uncertainties which lead not only to financial losses, but also to motivational and reputation damages; the need of developing knowledge of risk management in construction industry becomes essential. This risk management study focuses on the airport construction projects (ACPs) which are designed not to have only terminal building with its ancillary buildings, but also to have hotels, conference halls and recreation areas which make them to be distinguished from the others. High interaction between the stakeholders like investors, contractors, consultants, suppliers, employees, travelers, customers who are interested in airport retail areas reinforces this need. Contribution to the literature which suffers lack of risk-related studies on ACPs is the other motivation of this study by which it is aimed to warn project managers who are willing to work for ACPs for the risks and risk management methods. For the purpose of analysing the risks in ACPs, semi-structured interviews were conducted with the experienced company managers, project directors and managers, consultants, department leaders, and prominent subcontractors' representatives. The results of the semi-structured interviews were assessed by Analytic Network Process (ANP) since it is easier and more convenient method to apply for numerous criteria and assessing the results comparing to others. In addition, financial and technological risks were assessed deeper by simulation techniques like Monte Carlo Analysis. The results of these qualitative and quantitative techniques applied are reported to enlighten the ways of project managers and other stakeholders for the risks in ACPs.

## ■ TD-17

Thursday, 14:45-16:15 - Seminarraum 310

### Supply Chain Reliability and Risk

Stream: Supply Chain Management

Chair: *Moritz Fleischmann*

#### 1 - Supply Chain Reliability and the Role of Individual Suppliers

*Simeon Hagspiel*

We study a one-period supply chain problem consisting of numerous suppliers delivering a homogeneous good. Individual supply is uncertain and may exhibit dependencies with other suppliers as well as with the stochastic demand. Assuming that reliability of supply represents an economic value for the customer that shall be paid accordingly, we first derive an analytical solution for the contribution of an individual supplier to supply chain reliability. Second, applying concepts from cooperative game-theory, we propose a payoff scheme based on marginal contributions that explicitly accounts for the statistical properties of the problem. A number of desirable properties is thus achieved, including static efficiency as well as efficient investment incentives. Lastly, in order to demonstrate the relevance and applicability of the concepts developed, we consider the example of payoffs for reliability in power systems that are increasingly penetrated by interdependent variable renewable energies. We investigate empirical data on wind power in Germany, thereby confirming our analytical findings. In practice, our approach could be applied to design and organize supply chains and their reliability more efficiently. For instance, in the field of power systems, the approach could improve designs of capacity or renewable support mechanisms.

#### 2 - Total Supplier Risk Monitoring - Wissensmanagement als Grundlage einer präventiven Lieferantenbewertung

*Anja Wilde*

Durch die Verlagerung von Prozessen und Know-how in das externe Wertschöpfungsnetzwerk erhöht sich immer mehr die Abhängigkeit von Lieferanten. Somit werden neue Methoden zur Steuerung der SC notwendig. Eine effiziente und präventive Lieferantenbewertung erfordert dabei ein Wissensmanagement mit intelligenten Auswertungsalgorithmen. Dabei ist eine regelmäßige Bewertung aller Lieferanten, basierend auf einem gestuften Vorgehen mit Einsatz von Trends, Prognosen und Softfacts, notwendig. Darauf aufbauend kann Wissen über das externe Wertschöpfungsnetzwerk durch Korrelationen in einem Risikomuster erzeugt werden. Sind alle Informationen über die SC zusammengetragen, werden Muster in der Datenbasis zur präventiven Risikoabschätzung mit Hilfe von mathematischen Algorithmen gesucht. Ist ein Muster aufgefallen, können frühzeitig Rückschlüsse auf mögliche Risiken bei anderen Lieferanten mit einem gleichen oder ähnlichen Musteranteil gezogen werden, die noch nicht negativ in Erscheinung getreten sind. Diese Informationen sind jedoch nur so valide, wie die Datengrundlage selbst. Sind die Grunddaten der genutzten Kennzahlen fehlerhaft oder unvollständig, ist das generierte Wissen über die Risiken in einer Lieferanten-Abnehmer-Beziehung nicht belastbar. Somit werden alle Daten einem Test (Datachecker) unterzogen, in dem die Daten auf Validität, Konsistenz und Plausibilität überprüft werden. Die Identifikation der relevanten Risiken in der Supply Chain und deren Messung durch Kennzahlen bilden die Basis für ein Wissensmanagement, welches ein effektives Risikomanagement ermöglicht. Durch den ganzheitlichen Ansatz mit Hilfe von innovativen Methoden und künstlicher Intelligenz wird das externe Wertschöpfungsnetzwerk effizient und präventiv gesteuert.

## ■ TD-18

Thursday, 14:45-16:15 - Seminarraum 401/402

### Liner Shipping Optimization II (i)

Stream: Logistics, Routing and Location Planning

Chair: *Kevin Tierney*

#### 1 - Design of Container Liner Services - A literature Review and Simulation Results

*Jürgen Böse, Joachim R. Daduna*



The presentation is canceled. 05.08.2016, Juergen Boese

Today, scientific literature provides numerous publications for the design of liner services in container shipping. The contribution presents a review of related publications associated with a survey of (quantitative) methods and concepts used for service design. Moreover, the related approaches are critically evaluated regarding their benefit for problem solving in practice. A second part of the contribution introduces the main results of a simulation study systematically analyzing the impact of liner service parameters (e.g., vessel size and speed or number of loop ports and vessels) and operational conditions (e.g. "weather") on performance and economic figures of services.

## 2 - A chance constrained approach for heterogeneous fleet scheduling in liner shipping service

*Sinan Gürel, Aysan Shadmand*

We deal with a schedule design problem for a heterogeneous fleet of liner shipping service under uncertain waiting and handling times. Due to variability in waiting and handling times, ships may depart later than the published schedule which deteriorates customer satisfaction. We measure service level at a port as the probability of on-time departure of a ship from that port. The problem is to determine the departure times at ports and speeds of ships on each leg so as to minimize the total fuel burn while satisfying an overall target service level. We consider three new aspects of the problem. The first one is heterogeneous fleet where each ship type may have different fuel efficiency. The second one is considering critical ports in schedule, i.e. considering the fact that on-time performance at critical ports might be more important for the shipping company. Third one is proposing a new service level measure for the schedule of a liner shipping company. We propose a chance constrained nonlinear mixed integer programming formulation for the problem. We employ second order cone programming inequalities to solve the problem. Finally, several experimental factors are defined and effects of these factors on fuel consumption cost and optimal solutions are analyzed.

## 3 - Service Design for Liner Shipping with Service Levels

*Kevin Tierney, Jan Fabian Ehmke, Ann Campbell*

We consider the liner shipping route design problem, where each port has a time window, and travel times between ports are assumed to be stochastic. Service reliability and on-time arrival guarantees are important for many liner shippers and carriers, but have not been addressed in the literature for building new routes. To this end, given a set of ports with time windows when they can be visited, we construct new routes ensuring that each time window is satisfied with a given service level while minimizing the costs of a single route. We investigate how different service levels affect the costs of a route, and allow the model to increase the speed of a vessel to ensure the service level. Finally, we analyze the trade-off between vessel costs and the costs of speeding.

## ■ TD-19

*Thursday, 14:45-16:15 - Seminarraum 403*

## Passenger Routing in Public Transportation Problems (i)

Stream: Traffic and Passenger Transportation

Chair: *Jonas Harbering*

### 1 - Causal structure learning on travel mode choice based on structural restrictions and model averaging algorithm

*Tai-yu Ma, Joseph Y.J. Chow, Jia Xu*

This work contributes to develop a new heuristic methodology to overcome the NP-hard complexity of identifying and estimating the causal structure of travel mode choice as a Bayesian Network (BN). We propose an algorithm as a two-stage procedure by first drawing relevant prior partial relationships between variables (i.e. structural restriction) from our domain knowledge, and then using them as structure constraints in a BN structure learning task. The latter is performed using the model averaging approach (Korb and Nicholson, 2010) to obtain a statistically sound BN. Two experiments are set up to test the effects of structural restriction and model averaging approach on the obtained

BN structures. The first experiment compares the obtained BN structures with and without the restrictions. The second experiment is related to the effect of resampling size in the model averaging method for identifying significant arcs in the best BNs and to determine which learning algorithm is more effective. Different BN structure learning algorithms (Hill-Climbing algorithm, Max-Min Hill-Climbing algorithm and Incremental Association algorithm) have been tested. The results show the proposed method can effectively improve the quality of obtained BNs structures. The advantage of BNs is that it can capture more sophisticated relationships between the variables that are missing in both decision tree models and random utility models. Empirical study for travel mode choice behavior modeling is based on the mobility survey of the cross border workers of Luxembourg in 2011.

### 2 - Predictive Clustering of Public Transport Boarding Data for Planning and Smart Passenger Information Systems

*Uğur Eliyi, Efendi Nasibov*

We consider a clustering problem involving the analysis of passengers using a multimodal public transportation system in Izmir, Turkey. Daily ridership of the network in four transport modes of bus, ferry, metro and suburban rail systems amounts to 1.8 million boardings on the average. The city has employed an electronic fare collection system since 1999, which integrates existing and newly built rail systems, and handles ticketing operations and gathering boarding information from contactless smart cards. Each boarding record contains the time, location, mode, route, vehicle, and fare data for the individual trip. A large portion of the urban central network zone allows free transfers between all modes. Moreover, some passenger fare types are defined to waive the boarding fees of the disabled and senior citizens totally, or students and teachers partially, regardless of trip times or modes.

In this study, we examine the individual trip patterns of passengers according to different fare types, boarding locations (bus stops, stations, piers, major intermodal transfer centers, schools, hospitals, etc.) and daytimes over a moving horizon of consecutive days. By observing repetitive transfer points, times or preferred route information of regular passengers, self-organizing maps are formed for clustering trips by fare type, origin location and boarding time. In this manner, it is possible to predict the trip behavior of passengers according to specific criteria, determining final destinations, mode choice, reason for trip (work, school or leisure) and vehicle congestions. A Kohonen network is designed, which will help to form an important information base for both transport planning purposes and trip planning applications in passenger information systems.

### 3 - Delay Resistant Line Planning with a View Towards Passengers' Transfers

*Jonas Harbering*

In modern public transportation networks, delays are the main issue for disturbing smooth operations and hence the dissatisfaction of passengers. This work is intended to show gains achievable by considering measures reducing the impact of delays when planning a public transportation network. Important phases in the planning of a public transportation system are, among others, line planning, timetabling and delay management. The delay resistance of such a system is usually measured at the delay management stage. The measures which are to decrease the effect of delays are usually taken at the stages of timetabling (adding buffer, rearranging slack times) and delay management (developing methods which prevent the spreading of delays). One major reason for the propagation of delays, which is not controlled by those measures, are the passenger transfers. They can even be handled at the line planning stage. In the literature there exists only few work studying the implication of the line planning stage towards delay resistance. Hence, the aim in this work is to provide a line planning model which forms the basis of highly delay resistant public transportation systems. The idea is to explicitly take control of the passenger paths which allows to minimize the number of passenger weighted transfers in the line planning problem. By this a positive effect towards delay resistance can be recognized. We present an algorithmic solution procedure, which is shown to give the optimal solution on small instances. Furthermore, the transfer-minimizing line planning model is compared to other well-known line planning models - e.g., cost model, direct travelers model - by computing a timetable of similar quality, introducing and propagating delays, and measuring their delay resistance.

## ■ TD-20

Thursday, 14:45-16:15 - Seminarraum 404

### Sequential and Temporal Data Analysis

Stream: Business Analytics and Forecasting

Chair: *Julian Bruns*

#### 1 - Reducing debiasing model uncertainty with revisioning

*Florian Knoell, Thomas Setzer*

In today's enterprises, the accuracy of forecasts is of crucial importance to corporate decision-making and planning quality. For instance, in corporate reporting and planning systems expert cash flow expectations are consolidated in order to derive liquidity plans and managerial means to hedge expected foreign exchange risks. However, usually local experts of a corporation's subsidiaries generate cash flow forecast data in a decentralized fashion. As human judgment is known to be prone to cognitive biases, in the literature it has been regularly found that by diagnosing biases in past forecasts and applying models to remove the determined biases in future forecasts increases accuracy and improves overall decision making.

But the conditions often change and therefore the strength and influence of bias might change as well. With a change of bias the outcome of correction methods become uncertain. However often corrections conducted automatically will actually increase instead of decrease error. We argue that if an expected bias in a judgmental forecast takes place, there also should be evidence for biased decision making the way the expectations have been revised before deriving the final forecast. This evidence should overall increase the confidence in whether a correction is advised or not.

We use known and novel measures to characterize the structure in revisioning and use these measures as features for prediction if a correction or the original estimate is favorable. The approach is evaluated using empirical cash flow forecast data of a large international corporation. Results show a significant reduction of uncertainty whether a correction is beneficial for further forecasting.

#### 2 - Metrics and Aggregation Mechanisms for Temporal Information in Sequential Data

*Katerina Shapoval, Thomas Setzer*

Nowadays, large amounts of data are available for analysis. The sequential type of data, which accumulates e.g. about customer purchases over time, implies large combinatorial complexity stemming from exponential growth of possible sequence instances with respect to sequence length and number of possible sequence symbols. Often, such information is aggregated by simple ways, e.g. by count functions or binary representations for occurrence of sequence symbols, as predictive models often are not able to handle such high-cardinality features. Several approaches exist to handle sequential information; some of these exploit temporal discounting for weighting more recent information higher, which is reasonable for most applications.

In this paper we first propose metrics for estimation of additional predictive value of sequential information compared to simple aggregation techniques prior to incorporation into a class-prediction model. Second, we link this metrics to an appropriate discounting factor and number of segments for sequence aggregation method, so that approximate optimal level for these parameters can be determined upfront. Proposed metrics are then evaluated on a data set of a telecommunications provider, which offers different product and services on international market. The results demonstrate the ability of proposed metrics to capture the added value of sequential information and to serve as a guiding value for model parametrization.

#### 3 - Forecasting local temperatures in urban context

*Julian Bruns, Boris Amberg, Thomas Setzer*

It is known that cities are typically hotter than their surrounding areas as a result of impervious surfaces that drive temperatures. This phenomenon has been coined Urban Heat Island (UHI). One regularly observes also large temperature differences and local extremes within the scope of a city itself, denoted as Intra-Urban Heat Islands. The determination, anticipation, and avoidance of such UHI is crucial to human health of citizens and of pivotal importance for proactive health-aware city planning. Unfortunately, high spatial resolution of temperature differences within a city received scarce attention in the literature so far. Standard procedures for UHI assessment either measure a whole urban area (or large portions of it) by satellite images (with low spatial

resolution), or point measurements available only at fixed weather stations, with low overall density. Hence, the heat-information we gain from such models are either rather coarse-grained or valid for single geo-coordinates only, and are thus of limited value for city planners. We propose a joint model relating satellite measurements of land surface temperature to ground based measurements of air temperature. By including the relative position of each ground based point as well as the land use to a number of nearest satellites, we predict temperatures for small areas such as streets throughout a city. To model the inherent volatility of the forecast we use approaches like Bayesian hierarchical modelling. Based on residual diagnostics we determine areas that are well predictable versus areas with high error variance to recommend promising points of interest, based on a hot spot analysis, for the placement of additional weather stations within a city to improve overall prediction in an economic fashion.

## ■ TD-21

Thursday, 14:45-16:15 - Seminarraum 405/406

### Bi-Objective Vehicle/Ship Routing

Stream: Logistics, Routing and Location Planning

Chair: *Kjetil Fagerholt*

#### 1 - Finding the trade-off between gas emissions and disturbance in an urban context

*Jasmin Grabenschweiger*

We introduce the bi-objective emissions-disturbance TSP (BEDTSP) that aims at the simultaneous minimisation of gas emissions and disturbance in the context of delivering customers in urban areas. The objective of total emissions is assumed to be dependent on travelled distance and carried load weight. With the objective function of disturbance we want to measure how much residents are affected by noise, pollution, risk, vibration, etc. caused through traffic resulting from freight transportation. We identify population density to be a proper indicator for this. So the more people are living next to a street the more disturbing it is. The particularity of disturbance data is that the triangle inequality does not hold for it because the shortest distance path between two points may go through very densely populated areas, whereas a detour through sparser populated areas may yield less disturbance. We present several bi-objective mixed integer programming formulations for the BEDTSP. In a first, rather naive model only the shortest distance paths between nodes are considered. Three more sophisticated models are then introduced that all make use of the idea to use other paths than the shortest distance one in order to decrease total disturbance of a tour (at the expense of emissions). Computational experiments on randomly generated instances show up the benefits and shortcomings of the different approaches - in terms of solution quality as well as CPU performance. Moreover, a real world case study is conducted in order to compare the solutions of our problem to tours carried out in reality.

#### 2 - The bi-objective k-dissimilar vehicle routing problem

*Sandra Zając*

In cash-in-transit operations, significant amounts of money need to be delivered or picked up from a set of customers. As a result, a significant risk of robbery arises. A potential approach to decrease this risk is to generate  $k$  spatially dissimilar vehicle routing alternatives. By periodically changing the routes to dissimilar ones, the unpredictability of the actually driven routes can be increased which in turn can reduce the risk of robbery. An alternative to the  $k$ -dissimilar vehicle routing problem is therefore a set of  $k$  distinct routing alternatives. We assume that it will only be accepted by the decision maker if the difference between the distance of the longest routing alternative in the set and the distance of the best known routing alternative in the considered instance is within reasonable limits. Since the  $k$  shortest routing alternatives are often similar to each other, the  $k$ -dissimilar vehicle routing problem is inherently a bi-objective problem. We examine the tradeoff between the minimization of the distance of the longest routing alternative in the set and the maximization of the minimum dissimilarity between two routing alternatives in the set for  $k > 1$ . We further simplify the computation of an intuitive spatial dissimilarity metric taken from literature to measure the dissimilarity between two routing alternatives. An approach to approximate the Pareto set of all Pareto optimal sets of  $k$  routing alternatives with respect to the two introduced criteria is presented. The solution concept is tested on selected instances of the capacitated vehicle routing problem. The results are promising and,

using the hypervolume indicator as a solution quality metric, suggest that the approach is able to find a good coverage of the true Pareto front for varying  $k$ .

### 3 - Bi-objective optimization in offshore supply vessel planning

*Kjetil Fagerholt, Thomas Borthen, Henrik Loennechen, Xin Wang*

We consider the supply vessel planning problem (SVPP) faced by Statoil, the largest oil and gas company operating on the Norwegian continental shelf. A set of offshore installations requires supplies by a chartered fleet of offshore supply vessels (OSVs) from an onshore depot on a regular basis. The problem in its original form consists of determining the fleet of OSVs and their corresponding weekly routes and schedules that minimize the total chartering and operating costs. The SVPP is closely related to the periodic vehicle routing problem, except for that in the SVPP each route will typically span two to three days. Furthermore, Statoil maintain the given weekly schedule for a longer period until some changes in input parameters occur, such as for example the arrival of new drilling rigs that require services. The planners then need to update the existing plan. An important requirement is to keep the new plan as close to the previous one as possible with respect to at which days the offshore installations get services. This introduces an additional persistence objective in addition to the costs and the SVPP becomes a bi-objective planning problem.

Since the SVPP with persistence has two objectives, we aim at generating a Pareto front of optimal solutions. We propose an exact solution method based on a path flow formulation of the problem. Since we are only able to solve medium-sized problems with this approach we also propose a hybrid genetic algorithm that combines the exploration breadth of population-based evolutionary search, the improvement capabilities of local search, and advanced population diversity management schemes. It is shown through a computational study that the proposed algorithm performs very well and can provide valuable decision support.

**Thursday, 16:30-18:00**

## Friday, 9:00-10:30

### ■ FA-02

Friday, 9:00-10:30 - Hörsaal 1

#### Paths, Trees, and Tours

Stream: Discrete and Integer Optimization

Chair: *Corinna Gottschalk*

##### 1 - Asymmetry Helps: Dynamic Half-Way Points for Solving Shortest Path Problems with Resource Constraints Faster

*Stefan Irnich, Timo Gschwind, Ann-Kathrin Rothenbacher, Christian Tilk*

With their paper 'Symmetry helps: Bounded bi-directional dynamic programming for the elementary shortest path problem with resource constraints' [Discrete Optimization 3, 2006, pp. 255-273] Righini and Salani introduced bounded bidirectional dynamic programming (DP) as an acceleration technique for solving variants of the shortest path problem with resource constraints (SPPRC). SPPRC must be solved iteratively when vehicle routing and crew scheduling problems are tackled via Lagrangian relaxation or column generation techniques. Righini and Salani and several subsequent works have shown that bounded bidirectional DP algorithms are often superior to their monodirectional counterparts, since the former can mitigate the effect that the number of labels increases strongly progressively with the path length. Bidirectional DP has become a quasi-standard for solving SPPRC. In computational experiments, however, one can still observe that the number of forward and backward label extensions is very much unbalanced despite a symmetric bounding of a critical resource in the middle of its feasible domain. We exploit this asymmetry in forward and backward label extensions and introduce a so-called dynamic half-way point, which is a dynamic bounding criterion based the current state of the simultaneously solved forward and backward DPs. That dynamic half-way points better balance forward and backward workload is confirmed by experiments with the following problems: the vehicle routing problem and the pickup-and-delivery problem with time windows, the vehicle routing and truck driver scheduling problem with time windows, and the truck-and-trailer routing problem with time windows.

##### 2 - On the minimum quartet tree cost problem

*Sergio Consoli, Jan Korst, Gijs Geleijnse, Steffen Pauws*

Given a set of  $n$  data objects and their pairwise costs (or distances), the goal of the minimum quartet tree cost (MQTC) problem is to construct an optimal tree from the total number of possible combinations of quartet topologies on  $n$ , where optimality means that the sum of the costs of the embedded (or consistent) quartet topologies is minimal. Since the MQTC problem is an NP-hard combinatorial optimization problem, some metaheuristics have been proposed in the literature. Here we summarize the details of the heuristics to date for the problem and provide the preliminaries for an exact solution approach under development.

##### 3 - Better s-t-Tours by Gao Tree

*Corinna Gottschalk, Jens Vygen*

We consider the s-t-path TSP: given a finite metric space with two elements  $s$  and  $t$ , we look for a path from  $s$  to  $t$  that contains all the elements and has minimum total distance. We improve the approximation ratio for this problem from 1.599 to 1.566. Like previous algorithms, we solve the natural LP relaxation and represent an optimum solution as a convex combination of spanning trees. Gao showed that there exists a spanning tree in the support of the LP solution that has only one edge in each narrow cut (i.e., each cut with total LP-value less than 2). Our main theorem says that the spanning trees in the convex combination can be chosen such that many of them are such "Gao trees" simultaneously at all sufficiently narrow cuts. This can be used for an improved analysis of the best-of-many Christofides algorithm.

### ■ FA-03

Friday, 9:00-10:30 - Hörsaal 2

#### Resource and Energy Efficiency

Stream: Energy and Environment

Chair: *Magnus Richter*

##### 1 - Coordination mechanisms for decentralised production planning in energy-flexible factories: matching theory and applications

*Lukas Strob, Thomas Volling*

The trend towards an increasing share of renewables results in time- and weather dependent fluctuations in energy supply. Energy-flexible factories seize this opportunity by actively participating in the energy trading or balancing markets. For this purpose, appropriate flexibility instruments need to be installed as part of the production planning process. Current planning approaches assume centralized decision making regimes based on monolithic models. Yet, reality is usually different. In order to handle complexity, factories are organised in different production sections that are managed partially autonomous as business units and cost centres. The question arises how to coordinate the decentral plans of these production sections in a way that is efficient and favourable for the entire factory.

We analyse the suitability of common coordination mechanisms known from the literature to facilitate energy-flexible factories. Based on the application-oriented analysis of distributed production planning in energy-flexible factories we derive requirements for coordination mechanisms. We discuss how common coordination mechanisms such as auctions and iterative solution procedures are suitable to achieve an efficient coordination of flexibility plans in a network of several production sections. Additionally, we present results of a numerical example and point out issues for future work.

##### 2 - Deployment and relocation of semi-mobile facilities in a thermal power plant supply chain

*Tobias Zimmer, Patrick Breun, Frank Schultmann*

Co-firing of biomass in coal-fired power plants is considered one of the most economic ways of carbon dioxide abatement. We investigate the deployment and relocation of several semi-mobile processing facilities in order to supply a large coal-fired power plant with high-quality renewable energy carriers. Semi-mobile facilities are characterized by a containerized design and can be relocated in case of changes in supply and demand. The energy carriers which are produced by different types of semi-mobile technologies are bulky goods with high density and properties comparable to those of coal and fuel oil. Thus, intermodal transportation is required to achieve transportation costs which are competitive with the delivered cost of fossil fuels at the plant's gate. The optimization of the investigated supply chain therefore requires simultaneous planning of semi-mobile facility deployment and intermodal transportation. To this end, we present a mixed-integer linear problem which optimizes the number of semi-mobile facilities, their respective relocation over time and the intermodal transportation of produced energy carriers to the power plant. In the presented case, train transportation is characterized by a low geographical coverage of the railway network and restrictions representing minimum shipping volumes per railway line. The model minimizes the objective function of total supply chain costs including electricity generation, transportation, the operation and relocation of the semi-mobile plants and the necessary forestry operations associated with the deployed facilities. The model is implemented in GAMS and solved using the CPLEX solver. We discuss a numerical example based on data from the forestry and energy sector in Chile.

##### 3 - An investment planning approach for energy and resource efficiency measures for cross-sectional technology

*Matthias Gerhard Wichmann, Ina Schlei-Peters, Thomas Spengler*

Due to legislation, cost pressure and customer requirements, industry is faced with the need to increase energy and resource efficiency. To increase energy and resource efficiency of specific production systems, often numerous technological starting points or measures are known. Here, starting points only relate to technological parameters which could be changed in order to change efficiency. In contrast, measures explicitly describe technological and organisational changes in a production system. This also holds for cross-sectional technology. For both, the quantitative effects regarding the change of mass and energy flows in a production system are hard to estimate. If there are several measures which allow for an improvement, assessment methods for measure combinations are sparse. Further, investment planning on efficiency measures is necessary. Here, from all possible efficiency measures those have and their implementation point of time to be selected, which can be implemented with a given budget in order to reach or exceed predetermined efficiency objectives. Investment planning approaches, which allow for the consideration of interdependencies

between individual measures are sparse as well. In our contribution an investment planning approach for energy and resource efficiency measures in complex production systems is given. The approach comprises a modelling approach of complex production systems, which allows for the quantification of relations between starting points and efficiency measures and their impact on energy and material flows in the production system. Based on the modelling, an investment planning model is introduced. The planning approach is applied to a case study of a cooling system. As a result the energy efficiency can be increased by 16%.

## ■ FA-04

Friday, 9:00-10:30 - Hörsaal 3

### Optimisation and decomposition in energy markets

Stream: Energy and Environment

Chair: *Michael Zipf*

#### 1 - Two-stage Robustness Trade-off: TRusT in the design of energy systems

*Dinah Elena Majewski, Marco Wirtz, Matthias Lampe, Andre Bardow*

Designing energy supply systems aims at finding a configuration of energy conversion units that covers all energy demands at minimal expenses. The resulting complex design problems are best addressed by employing mathematical optimization. However, energy demands and prices are usually uncertain. Assuming certainty for the data yields suboptimal or even infeasible solutions: If energy demands are higher than assumed during design, a lack of supply occurs for the optimal solution. To incorporate uncertainties in the optimization to guarantee security of energy supply, robustness concepts can be employed. However, strictly robust solutions are very conservative in general and often expensive.

We propose the Two-stage Robustness Trade-off (TRusT) approach to design energy supply systems that are both cost efficient and strictly robust. The TRusT approach is based on bi-objective optimization evaluating the trade-off between nominal costs and robust costs. Thereby, the TRusT approach reflects the inherent two-stage nature of energy system optimization: The first stage is the design of the energy system; the second stage determines the operation of each unit in the system and can be adapted to the occurring scenario after the design is fixed. The TRusT approach evaluates how strictly robust designs perform in the nominal and the worst-case scenario.

In a real-world case study, we identify a strictly robust design which increases the nominal total annual costs only by 1.2 % compared to the nominal optimal design. The results show that the TRusT approach reveals strictly robust design options which guarantee security of energy supply at low additional costs.

#### 2 - Optimization Problem for the Installation of Equipment to Control Power Flow

*Takayuki Shiina, Jun Imaizumi, Susumu Morito, Chunhui Xu*

We consider the optimization problem with combinatorial constraints that represent the installation of the equipment to control the power flow, called loop controller. The installation of the equipment is formulated as a mixed integer programming problem. Its solution is difficult because the calculation of optimal power flow is a non-convex and nonlinear programming problem. In this problem, a set of scenarios of power demand is given as input data and the location for installation that minimizes cost under the operational constraints of the network is determined. These constraints are formulated as the voltage operating range and the line thermal capacity. A conventional technique used for the optimal installation resolves the mixed problem of combinatorial and nonlinear optimization, based on searching for a location of installation and computing the capacity for the equipment in two stages. If this type of technique is applied, then many cases might happen in a local search for the installation location in which no feasible flow exists. It is difficult to search the location efficiently. Thus, we present a new technique which approximates the installation cost without relying on local search. The approximation method called dynamic slope scaling procedure has the advantage that, this method always can provide a feasible solution. Since the method does not include 0-1 variables representing the installation, and so always retrieves a feasible value for

the location and power flow. Finally, the effectiveness of the developed technique is demonstrated.

### 3 - Benders Decomposition on Large-Scale Unit Commitment Problems for Medium-Term Power Systems Simulation

*Andrea Taverna*

The Unit Commitment Problem (UCP) aims at finding the optimal commitment for a set of thermal power plants in a Power System (PS) according to some criterion. Our work stems from a collaboration with RSE S.p.A., a major industrial research centre for PSs in Italy. In this context the UCP is formulated as a large-scale MILP spanning countries over a year with hourly resolution to simulate the ideal behaviour of the system in different scenarios. Our goal is to refine existing heuristic solutions to increase simulation reliability. In our previous studies we devised a Column Generation algorithm (CG) which, however, shows numerical instability due to degeneracy in the master problem. Here we evaluate the application of Benders Decomposition (BD), which yields better conditioned subproblems. We also employ Magnanti-Wong cuts and a "two-phases scheme", which first quickly computes valid cuts by applying BD to the continuous relaxation of the problem and then restores integrality. Experimental results on weekly instances for the Italian system show the objective function to be flat. Even if such a feature worsens convergence, the algorithm is able to reach almost optimal solutions in few iterations.

## ■ FA-05

Friday, 9:00-10:30 - Hörsaal 4

### Congestion Games (i)

Stream: Game Theory and Experimental Economics

Chair: *Max Klimm*

#### 1 - Approximate Pure Nash Equilibria in Cost Sharing Games

*Matthias Feldotto, Grammateia Kotsialou, Alexander Skopalik*

In this talk, we discuss the computation of approximate equilibria in cost sharing games. We consider weighted congestion games with polynomial cost functions for the resources. Compared to standard (weighted) congestion games, the cost functions are only given for the whole resource, but not for each player. A cost sharing method is then used to determine the costs of each player. Next to the trivial proportional cost sharing where each player has to pay a share proportional to her weight, the Shapley cost sharing method is the most accepted one since each player has to pay her marginal contribution to the overall costs. In this game setting, lots of research is going on. Especially, questions about the existence of equilibria and their quality are the topic of current research. We go one step further and look at approximate equilibria and especially the computation of them. In this talk, we present the game setting, some of its properties and our algorithmic approach.

#### 2 - Competitive Packet Routing with Priority Lists

*Daniel Schmand, Tobias Harks, Britta Peis, Laura Vargas Koch*

In competitive packet routing games, packets are routed selfishly through a network and scheduling policies at edges determine which packages are forwarded first if there is not enough capacity on an edge to forward all packages at once. We analyze the impact of priority lists on the worst-case quality of pure Nash-equilibria. A priority list is an ordered list of players that may or may not depend on the edge. Whenever the number of packets entering an edge exceeds the inflow capacity, packets are processed in list order. We derive several new bounds on the price of anarchy and stability for global and local priority policies. We also consider the question of the complexity of computing an optimal priority list. It turns out that even for very restricted cases, i.e., for routing on a tree, the computation of an optimal priority list is APX-hard.

### 3 - Bottleneck Routing with Elastic Demands

Max Klimm, Tobias Harks

Bottleneck routing games are a well-studied model to investigate the impact of selfish behavior in communication networks. In this model, each user selects a path in a network for routing their fixed demand. The disutility of a used only depends on the most congested link visited. We extend this model by allowing users to continuously vary the demand rate at which data is sent along the chosen path. As our main result we establish tight conditions for the existence of pure strategy Nash equilibria.

## ■ FA-06

Friday, 9:00-10:30 - Hörsaal 5

### Pricing and Service Design

Stream: Pricing and Revenue Management

Chair: Cornelia Schoen

#### 1 - Product Line Optimization in the presence of preferences for compromise alternatives

Georg Bechler, Claudius Steinhardt

Recent advances in customer choice modeling have demonstrated the strong impact of compromise alternatives on the behavior of decision-makers in a wide range of decision contexts. Compromise alternatives are defined as alternatives that have an intermediate performance on the relevant attributes. For example, it is well known from consumer research that customers often seek for price compromises in the sense that they tend not to buy the cheapest or the most expensive alternative from a given offer set. However, by now, such context effects are not considered in the literature on product line optimization.

In this talk, a new approach for optimal product line selection incorporating customers' preferences for compromise alternatives is proposed. It is based on a demand model that recently has been published in the econometric literature and includes compromise variables into a standard multinomial logit model. It is shown that the seller's resulting decision problem of optimal product line selection can be formulated as a fractional programming model. The formulation significantly differs from existing models of product line selection, as the endogenous effects of the chosen products or attribute levels on other alternatives' utility via the compromise variables has to adequately be captured.

#### 2 - Optimal Service Design at the Interface of Marketing and Operations: What Benefits to Provide to Customers, how to Create them, and what Price to Charge?

Fabian Strohm, Cornelia Schoen

Service design involves making decisions with regard to what benefits to offer to the customer (incl. what price to charge) and how to create these benefits. We present an integrated optimization approach for service design that links the design decisions on service pricing, service outcome and underlying front- and back-office service processes. Considering this interdependence allows to take into account service value and the costs of service delivery simultaneously. We thereby make a contribution to the problem of evaluating the financial performance of a service design, which has been identified as a top research priority in the service research community. Our problem formulation is very flexible with regard to what types of customer value propositions and production/delivery processes can be considered. Further, our optimization approach provides a standardized interface to common process modeling techniques such as flowcharts, blueprints, process chain network diagrams, or simulation models. As a result, our approach can be applied to a number of different business environments and industries, and selected case studies from a pizza delivery service and from a large railway transport service provider demonstrate real-world applicability of the optimization model. Regarding its mathematical structure, the initial problem formulation is nonlinear mixed-integer; however, we show how to transform it to a mixed-integer linear program.

#### 3 - Stochastic Multi-Product Pricing under Competition

Rainer Schlosser

Many firms are selling different types of products. Typically sales applications are characterized by substitution effects, limited information, and competitive settings. The demand intensities of a firm's products are affected by its own product prices as well as the competitors' product prices. Due to the complexity of such markets, smart pricing strategies are hard to derive. We analyze stochastic dynamic multi-product pricing models under competition for the sale of durable goods. In a first step, a data-driven approach is used to measure substitution effects and to estimate sales probabilities in competitive markets. In a second step, we use a dynamic model to compute powerful heuristic feedback pricing strategies, which are even applicable if the number of competitors' offers is large and their pricing strategies are unknown.

## ■ FA-07

Friday, 9:00-10:30 - Hörsaal 6

### Technical Applications of OR Methods (i)

Stream: Graphs and Networks

Chair: Armin Fügenschuh

#### 1 - Technical Operations Research and Technology Management

Ulf Lorenz

Within the last years, we have seen an increasing number of optimization applications for technical systems. Examples are advanced fluid systems, sticky separation in waste paper processing, or the synthesis of transmissions. The solution processes have been based on Discrete Mathematics and advanced algorithmics, mixed with the desire to model as near to Physics as possible. Therefore, Technical Operations Research is mostly associated with applying methods of Operations Research to the synthesis of technical systems. This, however, is only half of the truth. There is an additional dimension dealing with Technology Management, what we emphasize in this talk. Traditional engineering is based on the divide-and-conquer principle which has lead to bad systems with highly sophisticated components in various applications. Our task is to bring all the pieces together again and to design good systems consisting of the same highly sophisticated components. On the one hand, this is already a management task. On the other hand, Technical Operations Research also deals with the question, how the specialized research results of Discrete Mathematics, Algorithmics etc. can be made more ergonomic for users of other specialized segments of customers.

#### 2 - Particle-Image Velocimetry and the Assignment Problem

Armin Fügenschuh, Michael Breuer, Franz-Friedrich Butz, Jens Nikolas Wood

The Particle-Image Velocimetry (PIV) is a standard optical contactless measurement technique to determine the velocity field of a fluid flow for example around an obstacle such as an airplane wing. Tiny density neutral and light-reflecting particles are added to the otherwise invisible fluid flow. Then two consecutive images (A and B) of a thin laser illuminated light sheet are taken by a CCD camera with a time-lag of a few milliseconds. From these two images one tries to estimate the local shift of the particles, for which it is common to use a cross-correlation function. Based on the displacement of the tracers and the time-lag, the local velocities can be determined. This method requires a high level of experience by its user, fine tuning of several parameters, and several pre- and post-processing steps of the data in order to obtain meaningful results. We present a new approach that is based on the matching problem in bipartite graphs. Ideally, each particle in image A is assigned to exactly one particle in image B, and in an optimal assignment, the sum of shift distances of all particles in A to particles in B is minimal. However, the real-world situation is far from being ideal, because of inhomogeneous particle sizes and shapes, inadequate illumination of the images, or particle losses due to a divergence out of the two-dimensional light sheet area into the surrounding three-dimensional space, to name just a few sources of imperfection. Our new method is implemented in MATLAB with a graphical user interface. We evaluated and compare it with the cross-correlation method using real measured data. We demonstrate that our new method requires less interaction with the user, no further post-processing steps, and produces less erroneous results.

### 3 - A Mixed-Integer Nonlinear Program for the Design of Mechanical Transmission Systems

*Thorsten Ederer, Bastian Dörig, Peter Pelz, Marc Pfetsch, Jan Wolf*

Gearboxes are mechanical transmission systems that provide speed and torque conversions from a rotating power source. As central element of the drive train, they are relevant for the efficiency and durability of motor vehicles. Through decades of evolutionary improvements, modern gearboxes have become highly specialized systems – but their complexity has also increased and makes it difficult to adapt them to changes in the requirements. An novel approach to find alternative gearbox designs is needed.

A gearbox consists of multiple components, e.g., shafts, gear wheels, and sleeves. By changing the size and interconnection of these components, the total transmission ratios of the gearbox can be determined. However, each design comes with its own issues: a higher weight, a worse efficiency, or an impractical shape. On top of that, the load cases owing to motor-vehicle-pairings are often not clear a priori. Therefore, automobile manufacturers are confronted with a multicriteria design problem under uncertainty.

In this work, we present an approach on how to formulate the gearbox design problem as a mixed-integer nonlinear program (MINLP). This enables us to create gearbox designs from scratch for arbitrary requirements and – given enough time – compute provably globally optimal designs for a given objective. We show on realistic examples how different requirements and degrees of freedom influence the computation time and the resulting gearbox design.

## ■ FA-08

*Friday, 9:00-10:30 - Seminarraum 101/103*

### Liner Shipping Optimization I (i)

Stream: Logistics, Routing and Location Planning

Chair: *Kevin Tierney*

#### 1 - Modelling bunker consumption for optimization models in maritime transportation

*Daniel Mueller, Kevin Tierney*

In recent years, advanced mathematical models have been developed for optimizing a variety of optimization problems in the area of maritime transportation. A key cost in these models is the fuel consumption of vessels, which is known as the bunker consumption. As the industry seeks to reduce fuel consumption and CO<sub>2</sub> emissions as well, modelling variable speed has become a key component of maritime optimization. The bunker consumption varies approximately with the speed of a ship and proportionally to factors such as load and trim. Researchers have modeled bunker consumption in several different ways, including using linearized, piecewise linear or non-linear functions. So far, no rigorous study has been performed to see what affect the various approximations of bunker consumption have on the solution quality and the runtime of optimization approaches. To this end, we present preliminary computational experiments analyzing the runtime and quality of various approximations for the liner shipping cargo allocation problem. Our results suggest that simple modeling methods may provide equivalent solutions to more expensive ones.

#### 2 - Comparing Two Optimization Approaches for Ship Weather Routing

*Laura Walther, Srikanth Shetty, Anisa Rizvanolli, Carlos Jahn*

Weather routing in maritime shipping is related to a shipping company's objective to achieve maximum efficiency, economy and cost competitiveness by optimizing each voyage of a ship. A voyage can be optimized regarding costs, time, safety or combinations of these, while taking into account forecasted meteorological and oceanographic information as well as constraints given by geographic conditions, ship characteristics, emission regulations, safety requirements or time restrictions. A wide variety of mathematical models of the ship weather routing problem can be found in the literature. The formulations vary from constrained graph problems to nonlinear optimization problems and from one objective to multiple objective optimization problems. Numerous commercial systems and academic developments apply different approaches for solving the optimization problem, which range from calculus of variations, dynamic programming or discrete optimization methods to evolutionary methods. In this paper two ways to

approach the ship weather routing problem using a discrete optimization method on the one hand and an evolutionary algorithm on the other are presented. For both models, the ship's heading and its delivered engine power are introduced as control variables to allow route and speed optimization. The two approaches aiming at minimum fuel costs are compared based on numerical examples with real-world data.

#### 3 - Speed optimizations for liner networks with VSA and cooperation with feeders services, under workshift rules and piracy and emission control zones

*Line Reinhardt*

In liner shipping the increased focus on emissions and the low freight rates of maritime container freight increases the focus on green cost reduction measures. Clearly reducing fuel consumption also reduces the emissions resulting in a win-win situation. This study proposes a new model which for a fixed liner shipping network, minimizes the fuel consumption by adjusting the port berth times to allow for a more even speed throughout the service and thus a lower overall fuel consumption. This speed optimization is done while ensuring that given transit time limits for the carried cargo is satisfied, and considering the layover time for containers transshipping between services and delays are penalized. Workshift times and cost are included ensuring that changing the port visit time will not introduce an additional cost for the port operations. The model gives the global optimal solution for an entire network of container liner services and penalties for moving the port time is introduced to avoid the cumbersome work of changing port visit times when only negligible savings can be achieved. Results applying the model on real size liner shipping networks are presented.

#### 4 - Maritime Load Dependent Lead Times - An Analysis

*Julia Pahl, Stefan Voss*

Traditionally, the maritime sector including shipping lines, ports and terminals, as well as hinterland shipping service providers follows a very conservative approach towards developing and adopting IT ideas and concepts. Thus there lies a great potential for improvement among supply chain partners. We address this potential in analyzing the overall maritime supply chain in terms of lead times and focus on the current and future information needs and support of IT systems that facilitate information flows to enhance the forecasting and planning of the overall supply chain. Inspired by supply chain planning in manufacturing systems, we intend to analyze the applicability of well known concepts to the maritime supply chain and adapt/extend successful methodologies for maritime applications. We particularly emphasize on load dependent lead times, a phenomenon in production (planning) that refers to lead times of parts and products that are dependent upon resource utilization. Lead times increase exponentially with the utilization of the system, and this nonlinear dependency is rarely taken into consideration when resources are planned, such that planned and realized lead times may enormously differ.

## ■ FA-09

*Friday, 9:00-10:30 - Seminarraum 105*

### Evacuation Planning

Stream: Security and Disaster Management

Chair: *David Willems*

#### 1 - Interwoven systems modeling in civil security

*Stefan Ruzika, Kathrin Klamroth, Tobias Kuhn, Margaret Wiecek*

In civil security research, it is quite common that location decisions and transport decisions have to be made, e.g. when planning a large-scale evacuation. Location decisions might address gathering points or shelters, while transport decisions address evacuation routes and/or means of transport. Certainly, these two problems interfere with each other since the decisions of the one are input of the other. In situations like this, it is common to follow a linear or consecutive modeling approach. First, a location problem is solved and gathering points are computed and then, these are used as starting points for the transportation process. Although this modeling approach seems natural, it is not the only one possible and the question whether a different way of composing these two sub-models leads to better results suggests itself. This talk addresses the general question of how to decompose a complex, interwoven system into sub-systems. Different modeling paradigms are presented and relationships between them are studied. In particular, we

highlight an all-in-one model based on multiobjective programming and use this as a reference model for other composition/decomposition architectures. This research is motivated by civil security application, however we aim at a general theory.

## 2 - A complementary optimisation-simulation framework for a single- and biobjective timetabling problem

*David Willems, Carolin Torchiani, Stefan Ruzika*

For almost every large public event, a shuttle bus service is installed. At first, bus stops have to be chosen with respect to several criteria like distance to the event, space for waiting people et cetera. In this talk, we will focus on the security aspect, as we want to achieve that the total waiting time of visitors is minimised.

Since the travel routes from the bus stops to the event are fixed after locating the bus stops, a passenger's travel time cannot be influenced by the timetable. The only way to improve the quality of service is to reduce the waiting time of the passengers at the stops by using an in a sense optimal timetable.

We introduce a network flow based shuttle bus model that minimises the total waiting time of the passengers. The problem considered can be interpreted as a variant of a multicommodity flow problem over time. Both busses and passengers are represented by a commodity and the two flows are linked by a coupling condition. In contrast to usual timetabling problems, we assume that the passengers arrive within a certain timeframe.

At first we minimise the overall waiting time of the waiting passengers. We develop an IP-formulation and apply the model to a realistic scenario. Afterwards, we utilise a macroscopic simulation based on cellular automata to the optimal timetable in order to investigate the "quality" or robustness of such optimal timetables with respect to slightly perturbed input data like modified number of visitors, departure rules for delayed buses or different passenger behaviour concerning entering or getting of the bus, respectively. If the results of the simulation are not satisfactory to a practitioner, the corresponding input parameters can be changed and the optimisation-simulation cycle can be restarted.

## ■ FA-10

*Friday, 9:00-10:30 - Seminarraum 108*

### Robust optimization and applications

Stream: Optimization under Uncertainty

Chair: *Corinna Krüger*

#### 1 - A Robust Network Control Problem

*Kai Hennig*

Consider the following problem setup: Given a directed graph with arc capacities, supply values for the sources, and demand values for the sinks. Additionally, there is a robustness requirement as follows: For each sink, there is a second demand value, called peak value. It is previously unknown which of the sinks will their peak value instead of the normal demand.

A sink that takes on its peak demand value and for which the difference between it and the normal demand is distributed among the sources and added to their supplies, we call active. On the other hand, if a sink is marked, the additional supply can only be distributed among a previously defined, much smaller subset of the sources.

Given a fixed parameter  $k$ , the goal is to find the minimum number of sinks that need to be declared as marked in order to guarantee the existence of a feasible network flow no matter which  $k$  sinks are active and no matter how the resulting additional supplies are distributed.

In this talk we formally introduce the problem and formulate a mixed-integer tri-level optimization model. We discuss solution approaches as well as heuristic ideas.

An application for this problem arises in the context of modeling contracts on gas networks. Gas power plants are switched on while giving only very short notice to the transport system operator (TSO), and typically of them simultaneously in order to absorb peak loads from the associated electricity network. In general, these power plants are allowed to obtain their gas from any entry point of the gas network. But in anticipation of a bad distribution of demand and supply, the TSO has the right to restrict the power plants to a much smaller contractually fixed subsets of entries.

## 2 - The Robustness Gap in Multiobjective Linear Optimization with Decision Uncertainty

*Corinna Krüger, Anita Schöbel, Margaret Wiecek*

We investigate multiobjective optimization problems with uncertain decision variables, i.e., problems whose solutions cannot be put into practice exactly as planned. Examples for decision uncertainty can be found in the optimization of growing media in the horticultural sector, where mixing ratios can generally not be realized exactly due to the habit of working rather fast than exact. When aiming at a mixing ratio that is profitable and sustainable at the same time, a biobjective optimization problem with decision uncertainty is encountered.

The uncertain perturbations of the decision variables are considered as elements of a polyhedral uncertainty set. The uncertainty is modeled with a point-to-set map by adding the set of all possible perturbations to the considered decision variable. Hence, the robustness of efficient solutions is defined by a set rather than vector domination in the objective space.

We study multiobjective linear optimization problems (MOLPs) with decision uncertainty. We first show that the deterministic set-valued optimization problem being the robust counterpart (RC) to the original uncertain MOLP can be reduced to a deterministic MOLP over a restricted feasible set. While the latter can be easily solved with any suitable algorithm, it does not provide any information about the robustness gap, which is defined as the difference between two weighted objective values: that of an RC-efficient solution and that of an efficient solution for the worst-case scenario. To quantify this gap, we formulate a bilevel problem in which RC-efficient solutions are sought at the lower level, and a scenario that performs worst with respect to the active constraints at the RC-efficient solution is looked for at the upper level.

## 3 - Using Uncertainty Theory on the Facility Layout Problems

*Seyyed Hassan Taheri*

One of the most interesting and well-known problems in NP-hard combinatorial optimization and facility layout problems is the Quadratic Assignment Problem-QAP. Since it has many practical applications, such as allocation of facilities, design of electronic devices, etc. But in real-world the data of these problems are not exact. So we need a method that could solve this problem near the reality. In this research, we propose the Uncertainty Theory-UT tools for solving this problem. Moreover we considered Generalized Assignment Problem and solved it by UT tools. To demonstrate the efficiency of our method, we tested on 114 problems of QAPLIB and also on a data set we generated based on distribution of data of real-world problems. For solving this problem we used evolutionary algorithms. We compared our method with the best proposals from the related literature and we conclude that our method is able to report high-quality solutions and could be an effective in real-world problems.

## ■ FA-12

*Friday, 9:00-10:30 - Seminarraum 202*

### Combinatorial Optimization: Applications

Stream: Metaheuristics

Chair: *Peter Greistorfer*

#### 1 - Adaptive memory procedures for Max 3-SAT

*Peter Greistorfer, Cornelia Rainer, Gary Kochenberger*

For a long time, the many kinds of satisfiability (SAT) problems, Boolean decision problems from the general class of constraint satisfaction problems, have played an important role in operations research, information technology and in the area of artificial intelligence, as such also giving profound insights into computational complexity theory. For this work, we focus on the so-called Max 3-SAT problem, which has its applications, e.g., in satellite scheduling, frequency assignment for telecommunications or protein alignment in bioinformatics. Corresponding problem instances can be given by a number of conjunctive clauses, each of it with at most three Boolean disjunctive variables. The aim is to determine 0-1 variable values in order to maximize the number of clauses satisfied. The solution approach in this research is a prevalent metaheuristic one, therefore related to the general principles of adaptive memory programming, and builds on design options like greedy randomized selection rules, on recency and frequency memory



as well as on strategic oscillation. Technically, the problem is transformed into an equivalent nonlinear minimization problem by constructing an aggregated penalty function from classical constraints. We suggest two procedures. First, a construction procedure builds an initial solution using a variant of adaptive memory projection in a greedy randomized multi-start framework. Second, a tabu search algorithm, exploiting critical memory for switching the two groups of variables, is used to possibly improve the initial solution. The main concern is the presentation of comprehensive computational results for a vast number of instances known from relevant literature, thus enabling a detailed performance analysis of the solution procedures suggested.

**2 - A genetic algorithm for two-dimensional retail shelf space problems**

*Fabian Schäfer, Kai Schaal, Sandro Kühn, Alexander Hübner*

In order to maximize retail profits, retailers regularly determine how items should be allocated to retail shelves. One common characteristic in existent shelf space literature is the assumption that customers have a frontal perspective on shelves and observe only the foremost unit of an item, i.e. the facing. This implies that retailers must decide how to allocate the one-dimensional, front-row space by positioning different items side-by-side, but not behind one another. These types of optimization models are applied to standard supermarket shelves for the ambient assortment. However, there are other types of shelves which allow retailers to position two different items not only side-by-side but also behind one another. Examples are tilted shelves for meat, bread, fish, cheese or clothes. Customers have a total perspective on these shelves and can observe facings horizontally and vertically. This adds another degree of complexity to the shelf-space planning, because of the two-dimensional space restriction and shelf quantities need to be presented in a rectangular form. We develop the decision model, which optimizes the two-dimensional shelf-space assignment of items to a restricted, tilted shelf. We account for stochastic demand and space-elasticity effects. To solve the model we develop a genetic algorithm. By comparing it to a full enumeration, we proof its efficiency and show that results are near-optimal, with an average solution quality of above 99.1% in terms of profit.

**3 - Planning strategies of Smart Grids: An approach based on meta-heuristics and simulation**

*Ederson Santos, Carlos Teixeira, Marcelino Silva, Gizele Júlio, Diego Cardoso*

Smart Grids are regarded as the new generation of electric power systems (EPS), as aggregate in traditional systems the information and communication technologies that serve as an aid in energy management, particularly in regard to micro generation, auto recovery network, distributed generation through renewable sources, communication with smart meters, etc. Among the main benefits that this technology offers, are the ability to include consumers in process management and operation of the network, the ability to automatically detect, analyze, respond and restore failures, reducing the time and cost of maintenance, among others. However, this trend to be fully exploited, there are still a number of standards and research to be conducted. In this context, this work presents a meta-heuristic algorithm repeaters allocations in a Smart Grid, considering how data communication technology standard Power Line Communication (PLC). For this, there was the expansion of the IEC 61850 - Communication networks and systems in substations, considering the applications for Smart Grids on a power distribution scenario. The results, the optimized network, were tested in the NS3 software (Network Simulator) to analyze the performance of the optimized network as throughput, delay and to validate the data achieved. It is expected that the results achieved serve as a new tool for planning Smart Grid systems.

**■ FA-13**

Friday, 9:00-10:30 - Seminarraum 204

**Control Theory and Continuous Optimization**

Stream: Control Theory and Continuous Optimization  
Chair: *Behnam Soleimani*

**1 - On necessary optimality conditions for nonconvex vector optimization problems with variable ordering structures**

*Behnam Soleimani*

We consider nonconvex vector optimization problems with variable ordering structures in Banach spaces. Under certain boundedness and continuity properties we present necessary conditions for approximate solutions of these problems. Using a generic approach to subdifferentials we derive necessary conditions for approximate minimizers and approximately minimal solutions of vector optimization problems with variable ordering structures applying nonlinear separating functionals and Ekeland's variational principle.

**2 - A variational inequality formulation of migration models with random data**

*Fabio Raciti, Baasansuren Jadamba*

The last decade has witnessed a renewed interest in mathematical models of human migration. We consider here a model of economic equilibrium theory, which falls in the "micro" approach, i.e. it focus on the individual behaviour of migrants. The equilibrium conditions are equivalently written as a variational inequality, and we take into account the possibility that some of the data are only known through their probability distributions. We can then exploit the theory put forward in [1],[2], to compute the approximate mean values of the random solutions.

[1] J. Gwinner, F. Raciti, Some equilibrium problems under uncertainty and random variational inequalities, *Annals of Operations Research*, 200, 299-319 (2012)

[2] B. Jadamba, A. A. Khan, F. Raciti, Regularization of Stochastic Variational Inequalities and a Comparison of an  $L_p$  and a Sample-Path Approach, *Nonlinear Analysis A*, 94, 65-83 (2014)

**3 - Approximations and Generalized Newton Methods for Equations and Inclusions**

*Diethard Klatte, Bernd Kummer*

In this talk, we study local convergence of generalized Newton methods for both equations and inclusions by using known and new approximations and regularity properties at the solution. Including Kantorovich-type settings, our goal are statements about all (not only some) Newton sequences with appropriate initial points. Our basic tools are concepts and results on nonsmooth and generalized Newton methods published in the 1990ies, in particular those developed in the authors' book "Nonsmooth Equations in Optimization" (Kluwer 2002) about Newton maps and modified successive approximations. The talk is based on the authors' paper "Approximations and Generalized Newton Methods", *Optimization online*, February 2016.

**4 - Strong well-posedness for a class of hemivariational inequalities**

*Morteza Oveisiha*

The classical notion of well-posedness for the optimization problem, which has been known as the Tykhonov well-posedness, is due to Tykhonov [3]. A minimization problem is said to be well-posed if there exists a unique minimizer and every minimizing sequence converges to the unique minimizer. In the last decades, various kinds of well-posedness for optimization problems, such as Levitin-Polyak well-posedness, Hadamard well-posedness and well-posedness by perturbations has been introduced and studied by many researchers; see, e.g. [1,2,4] and references therein. In this talk, we consider a generalization of well-posedness for a class of hemivariational inequalities which include as a special case the classical variational inequalities. By using the Mordukhovich subdifferential for set-valued maps, we obtain a metric characterization for the well-posedness of hemivariational inequalities and give some equivalence results for them.

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1. X.X. Huang, X.Q. Yang and D.L. Zhu, Levitin-Polyak well-posedness of variational inequality problems with functional constraints, *J. Global Optim.* 44 (2009), pp. 159-174.
2. L.J. Lin and C.S. Chuang, Well-posedness in the generalized sense for variational inclusion and disclusion problems and well-posedness for optimization problems with constraint, *Nonlinear Anal.* 70 (2009), pp. 3609- 3617.
3. A.N. Tykhonov, On the stability of the functional optimization problem, *Comput. Math. Math. Phys.* 6 (1966), pp. 28-33.
4. Y.B. Xiao, X.M. Yang and N.J. Huang, Some equivalence results for well-posedness of hemivariational inequalities, *J. Global Optim.* 61 (2015), pp. 789-802.

## ■ FA-14

Friday, 9:00-10:30 - Seminarraum 206

### Simulation in Safety & Security & Social Science

Stream: Simulation and Stochastic Modeling

Chair: *Stefan Wolfgang Pickl*

#### 1 - OR in Modern Decision Support: The Case of Critical Infrastructure Protection

*Martin Zsifkovits, Stefan Wolfgang Pickl*

Modern states and cities are strongly dependent on a functioning infrastructure. This makes it even more vulnerable and attractive for terrorists. The situation gets even more severe when people are directly involved, such as in public transport, as they are - at least for some groups of terrorists - the main aim of attacks. In the BMBF funded projects RiKoV and RE(H)STRAIN we strongly consider OR techniques for getting an overall risk management framework in the domain of critical infrastructure protection. In a multilayered analysis, quantitative network analysis is coupled to fuzzy logic and agent-based simulation. Experiments, expert interviews, and table top exercises were used for parameterization and validation. The framework is applied to the case of public rail bound transport, where the analysis focuses on both, the macro and the micro view in the system.

#### 2 - A Macroscopic System Dynamics Model for a Generic Airport

*Maximilian Moll, Stefan Wolfgang Pickl, Jan-Peter Neutert, Andreas Tahedl*

The overall dynamics of an airport are multifaceted and very complex. With the ever increasing number of visitors everyday it is important to understand them. In this paper we present a new macroscopic system dynamics model of the overall workings of a generic airport. The model starts by distinguishing the various modes of transportation and their impact on the arrival rate. It continues to follow passengers through to the gates modelling various different behaviours on the way there. It concludes with fleet composition, the number of lanes and the impact on the noise level. Extra effort was taken to allow for the inherent stochasticity of many of these multi-layered processes. To make it more adaptive various on- and off-peak times are implemented as well.

#### 3 - Impact of Imitation on the Dynamics of Long Wave Growth

*Olivier Gallay*

Building on the insights of R. E. Lucas and M. Staley, economic growth emerges as the collective result of the productivity of a large collection (swarm) of individual agents. We assume that the individual productivity of each agent can be represented on an abstract line, where movement in the positive direction represents an enhancement in productivity. The evolution in each individual agent's productivity is idealized as a Brownian motion with a positive drift. This drift is composed of two parts. On the one hand, an individual component which takes the form of a positive constant and on the other hand, a time-dependent component resulting from the interaction with other agents. The latter component is interpreted here as an imitation mechanism, where the higher productivity state of leaders is to be a source of inspiration for laggards. The noise affecting the dynamics models the ubiquitous environmental uncertainties that affect the evolution of productivity over time. For a given agent, the imitation-based drift component depends in real-time on the number of productivity leaders detected within a range of observation and by their relative distance to the swarm's barycenter. For very large swarms, we are able to show that, depending on the strength of the imitation process, a bifurcation exists between two drastically different productivity propagation regimes. Weak imitation between the agents leads to a diffusive and evanescent productivity wave, which contrasts with strong imitation regimes, which can sustain strongly stable traveling productivity waves. These results indicate that policy makers need to promote economic frameworks that support and facilitate imitation processes between peers, and hence the diffusion of innovation within the society.

## ■ FA-15

Friday, 9:00-10:30 - Seminarraum 305

### Crew Scheduling

Stream: Project Management and Scheduling

Chair: *Michal Kohani*

#### 1 - Vessel Crew Scheduling in Ship Management - A Modelling Approach

*Erik Pohl*

One of the crucial tasks in Ship Management is the long-term crew scheduling where the future crew as well as the contract periods for each seafarer is determined under consideration of compliance requirements and scheduling rules. Depending on the size of the fleet and the number of seafarer, this problem can be hard to solve and it is usually done in a decentralized, short-term planning without modern decision support tools. In this contribution we consider both, the Contract Period Construction Problem (CPCP) and the Vessel Crew Scheduling Problem (VCSP) in Ship Management which together solve the long-term Crew Scheduling. We give an introduction to both problems, point out similarities and differences to other, known scheduling problems and put emphasis on some unique characteristics. Due to the special compliance requirement, such as rank, experience time and leave time of the seafarer or the defined deviation between crew changes, we are challenged with two complex problems. We present and discuss a MIP formulation for each problem and show first computational results. At last, we compare the determined solution with a hand-made operation schedule.

#### 2 - Efficient Ship Crew Scheduling complying with Resting Hours Regulations

*Anisa Rizvanolli, Carl Georg Heise*

To ensure safe ship operations, a safe and efficient schedule of crew tasks is necessary. This encompasses a work plan for the crew, consisting of appropriately qualified seafarers, which complies with the rules of the Maritime Labour Convention (MLC). The optimised crew schedule can reduce crew costs for shipping companies and also help to avoid expensive ship detentions by port state authorities due to incompliance in the crew's work plan. A mathematical model is presented for the crew scheduling problem, which is subject to complex rulesets for working and resting hours. In this model the mandatory tasks for safe ship operation and the crew qualification requirements for these tasks represent the main input parameters. They depend on variables such as the ship type and route and may differ substantially. Furthermore, the model considers common watch-keeping patterns and special constraints on mandatory tasks. This problem is formulated as mixed integer linear program. Numerical experiments with different real data sets from business practice are also presented. The purpose is to support shipping companies in their decisions on crew scheduling and safe ship operation with minimal costs.

#### 3 - Acceleration of the column generation method for the crew scheduling problem

*Michal Kohani, Jaroslav Janacek*

Crew scheduling is an important optimization problem in the railway industry. In last decades, the extension of computational resources made it feasible to address real-life problems generating generate large-scale set covering problems. Broadly used is the concept of shift frames, which is well suited current practice of several railway operators. In the case when the problem is described by one complete model, which covers all characteristics of the crew scheduling problem, it may lead to a large linear programming problem formulation, which can attack the limits of a common IP-solver. To overcome this obstacle, column generation technique can be used. Column generation technique can reduce the size of solved model. Despite the fact that it can not find the optimal solution, it can enable to solve larger instances. In this contribution we explain the concept of frames used in design of periodic timetable and analyse the property of the particular frame networks. We explain the column generating principle in connection with the crew scheduling problem. We present improving methods to accelerate the column generation method that are able to find solution of the solved sub-problem faster and different strategies of producing the initial collections of columns, which enable to make the column generation process more effective. To test proposed improvements we use various benchmarks of real problems from crew scheduling in railway transportation systems.

## ■ FA-16

Friday, 9:00-10:30 - Seminarraum 308

### Project Scheduling

Stream: Project Management and Scheduling

Chair: *Patrick Gerhards*

#### 1 - Introducing system dynamics functionalities in project management by playing a game

*David Rumeser, Margaret Emsley*

The importance of implementing System Dynamics (SD) in Project Management (PM) is due to the limitation of traditional PM methods resulting in gaps in PM practice. SD can fill these gaps by showing its uniqueness compared to the conventional PM methods, particularly in dealing with project complexity and dynamics. Project managers, however, may not be able to apply SD effectively without knowing how to use it correctly in their projects. Analogous to a tool (e.g. a knife) which can only be used properly when one knows its function (i.e. to cut things), SD will only be used effectively in PM if project managers know the functions it has, which are: ● As a communication tool; ● As a prediction tool (including scenario analysis); ● As a learning tool; ● As an optimization tool. This research shows and analyzes the four functions of SD in PM practice by designing and playing a web-based project management game called ManPro. The game is then discussed in the context of an example case study in project management.

#### 2 - Providing Lower Bounds for the Multimode Resource-Constrained Project-Scheduling Problem

*Christian Stürck, Patrick Gerhards*

We present lower bounds (LB) for the multi-mode resource-constrained project scheduling problem (MRCPS). In the MRCPS multiple execution modes are available for each activity. The aim of the MRCPS is finding a feasible schedule (maintaining all precedence and resource constraints) with a minimal makespan. The tested instances from the MMLIB have up to four renewable and non-renewable resources and the activities up to nine modes. Traditionally, the LB for the MRCPS are derived from the critical path method (CPM). Here, the mode with the shortest duration of each activity is chosen. We improve these LB. New earliest starting times (EST) are calculated by solving several integer programs with a standard solver. These new EST partially improve the EST calculated by the critical path method. This also reduces the number of variables in the model and, in the best case, proves optimality of the best known solutions. Computational results show that these new starting times provide a tighter bound than the LB obtained from the critical path method.

#### 3 - A hybrid metaheuristic for the multi-mode resource investment problem with tardiness penalty

*Patrick Gerhards, Christian Stürck*

In this talk we propose and analyze a hybrid approach for the multi-mode resource investment problem with tardiness penalty (MRIPT). The MRIPT is a project scheduling problem where, for a given deadline, the objective is to minimize the costs of resources allocated to the project as well as tardiness penalty costs for not respecting the given deadline. For each project activity multiple execution modes with differing resource requirements and durations are given. While the resource constrained project scheduling problem and its multi-mode extension have been extensively studied, the resource investment problem and especially its multi-mode extension received relatively little attention. In particular, we propose a large neighborhood search where destroy operators are applied to a feasible solution to obtain subproblems. These subproblems are solved with MIP-based recreate operators to obtain an improved solution.

## ■ FA-17

Friday, 9:00-10:30 - Seminarraum 310

### Sustainable supply chains

Stream: Supply Chain Management

Chair: *Eda Nur Çankaya*

#### 1 - A Decision Support System for Optimizing the Food Stock Distribution in Unilever

*Eda Nur Çankaya, Kübra Deligöz, Aylin Yağman, Tülin Aktin*

This study aims to develop follow up mechanisms to reach correct stock levels and provide quicker decision making in Unilever Food Solutions (UFS). Food products (Knorr, Calvé, Becel, Sana, Carte d'Or) are delivered to hotels, restaurants and catering companies via 40 distributors based on forecasting and replenishment stock models. These distributors offer service to four regions in Turkey. Purchase power, storage capacity and shelf life of products are three major criteria for them. However, mismatch between physical inventory and forecast data is the main problem, causing accumulated stocks or unsatisfied demand.

In order to overcome these issues, an Excel-based decision support system is designed to provide the balance between production and usage quantities, and to manage stock levels optimally. This system is integrated with the currently used softwares. Product and distributor data, annual/monthly target and realized sales data of Unilever and each distributor, instant stock status at distributors, age of products are some of the data retrieved from the existing system. The design phase has started by analyzing the problematic factors and determining the critical levels for each. Then, by applying Excel formulations, warning mechanisms are built according to these levels with the aim of giving a quick notification to the user, so that an immediate action will be taken. The developed system alerts the user on factors such as, remaining shelf life of products each week, differences between the monthly target and realized sales of distributors/Unilever, current stock and that month's closing stock kept by the distributor. The developed Excel-based control mechanism and its results are discussed with the managers of UFS, and found to be useful and applicable.

#### 2 - A mixed-integer linear programming for harvesting planing and transportation for coconut fruit supply chain in Chumphon province Thailand

*Pramote Kuson, Monsicha Tipawanna*

In this research, we used the mixed-integer linear programming model to meet the minimum cost for farmers to harvest and transportation for coconut fruit. The numerical results are presented to illustrate the feasibility of the real world coconut fruit harvesting and shipping model.

#### 3 - 3-D Printing as an Alternative Supply Option in Spare Parts Management

*Marko Jaksic*

3-D printing has lately received a considerable attention in the practical and research community. However the ways that the quickly developing technology will earn its spot in production environments and supply chains usually revolves around a radical redesign of conventional manufacturing and supply chain processes. We take a different approach, and explore how novel technology can be combined with existing operational practices to attain operational benefits. We study a spare parts continuous replenishment stochastic production/inventory problem of a manufacturer, where he has an option to source parts from a relatively inflexible conventional supplier ordering in large batches, or alternatively from a flexible in-house or outsourced 3-D printing facility. We derive the optimal policy and the optimal policy parameters for the hybrid sourcing strategy and compare its performance with the two single sourcing options. We show some of the relevant properties of the optimal policy, and reveal several managerial insights by means of numerical analysis.

## ■ FA-18

Friday, 9:00-10:30 - Seminarraum 401/402

### Complex Vehicle Routing Problems

Stream: Logistics, Routing and Location Planning

Chair: *Andreas Bortfeldt*

#### 1 - The capacitated vehicle routing problem with three-dimensional loading constraints and split pickup - a case study

*Junmin Yi, Andreas Bortfeldt*

The capacitated vehicle routing problem with three-dimensional loading constraints (3L-CVRP) combines vehicle routing and three-dimensional loading with additional packing constraints concerning, for example, the stability of packed goods. We consider a Shanghai automotive logistics company that serves many car makers in metropolitan Shanghai and whole China. The company performs milk-run operations in and around Shanghai where goods are picked up at different sites by identical vehicles. Often, the load of one site exceeds the volume capacity of a vehicle. Therefore, we focus on the 3L-CVRP with split pickup. We propose a hybrid algorithm for this problem. It consists of a tabu search procedure for routing and some packing heuristics with different tasks. One packing heuristic generates packing plans for shuttle tours involving sites with large-volume sets of goods. Another heuristic cares for packing plans for tours with greater numbers of sites. The hybrid algorithm is tested by a set of instances which differs from usual 3L-CVRP test instances but comes from real industrial data, with up to 46 sites and 1549 boxes to be transported. The algorithm yields good results within short computing times of few minutes.

## 2 - Combined manpower teaming and routing problem

*Yulia Anoshkina, Frank Meisel*

In the context of workforce routing and scheduling there are many applications in which workers must perform geographically dispersed tasks, each of which requires certain qualifications. In many such applications, a group of workers is required for performing a task due to the different qualifications of the workers. Examples are found in maintenance operations, the construction sector, healthcare operations, or consultancies. In this paper, we analyze the combined problem of composing worker groups (teams) and routing these teams, under various goals like minimizing total completion time. We develop mathematical optimization models for a sequential solution of the teaming problem and the routing problem as well as a combined model that includes both decisions. The resulting problem shares similarities with the VRP but it also differs in relevant aspects that result from the teaming decisions and the qualification requirements. Computational experiments are conducted for identifying the tradeoff of better solution quality and computational effort that comes along with combining the two problems into a single monolithic optimization model. We also discuss additional settings, where tasks require a cooperation of two or more teams.

## 3 - A Hybrid Algorithm for the Vehicle Routing Problem with Pickup and Delivery and Three-dimensional Loading Constraints

*Dirk Männel, Andreas Bortfeldt*

We extend the classical Pickup and Delivery Problem (PDP) to an integrated routing and three-dimensional loading problem, called PDP with three-dimensional loading constraints (3L-PDP). There are given a set of requests and a homogeneous fleet of vehicles. A set of routes of minimum total length has to be determined such that each request is transported from a loading site to the corresponding unloading site. In the 3L-PDP customer demands are represented as sets of parallelepipeds (called boxes) and the vehicle capacity is replaced by a 3D loading space. This allows for a more detailed modeling of mixed cargo transportation by vehicles. Several packing constraints, e.g. concerning stacking of goods, can only be considered if customer demands are viewed as sets of 3D items. In the problem formulation, we focused on the question under which conditions any reloading effort, i.e. any movement of boxes after loading and before unloading, can be avoided. A spectrum of 3L-PDP variants is introduced with different characteristics in terms of reloading effort. We propose a hybrid algorithm for solving the 3L-PDP consisting of a routing and a packing procedure. The routing procedure modifies a well-known large neighborhood search for the 1D-PDP. A tree search heuristic is responsible for packing the boxes. To ensure a reasonable computational effort, the integration of routing and packing is made according to the principle "evaluating first, packing second" and a cache for already checked routes is used. We tested the hybrid algorithm by using 54 newly proposed 3L-PDP benchmark instances with up to 100 requests (200 nodes) and up to 300 boxes. The results for the three 3L-PDP variants are plausible in that there is a clear tradeoff between travel distance and reloading effort.

## ■ FA-19

*Friday, 9:00-10:30 - Seminarraum 403*

### Applications of Timetable Optimization in Public Transport (i)

Stream: Traffic and Passenger Transportation

Chair: *Michael Kümmling*

#### 1 - Integrating Periodic Timetabling and Passenger Routing

*Heide Hoppmann*

Periodic timetabling is an important strategic planning problem in public transport. The task is to determine periodic arrival and departure times of the lines in a given network. Our goal is to minimize the travel time for the passengers, in order to provide an attractive transport system. This requires the consideration of the passengers' travel paths. We investigate periodic timetabling optimization models with integrated passenger routing and compare different variants. We show that the routing models have substantial impact on the quality of the timetable. We present computational experiments on real-world networks.

#### 2 - Periodic Timetabling for Fixed Driving and Waiting Times

*Julius Pätzold, Anita Schöbel*

Various investigations for solving the periodic timetabling problem in public transportation research make the assumption that a train (or a public transport vehicle in general) should travel between two consecutive stations in the least possible time. This assumption is even extended for the time a train waits at a station, meaning that these waiting times are also fixed to their minimal possible values. What remains to optimize are only the starting times of all lines. This should be done in such a way that the time passengers have to wait when changing between two lines that both stop at the same station is as small as possible. Since the times for staying within the same train are fixed, the resulting objective function minimizes the sum of all traveling times.

The first result presented is an investigation of how much the objective value of an optimal solution increases due to the aforementioned assumptions. Furthermore, some algorithms will be proposed for solving the timetabling problem with the described assumption. A special structure for solutions of this particular timetabling problem will be shown, which then allows to solve several instances exactly in reasonable time. For all remaining instances the idea of a matching-merge approach on the set of lines will be introduced in order to solve this special periodic timetabling problem heuristically. Numerical results for close-to real world instances will be presented.

#### 3 - Improving traffic assignment and periodic timetable optimization by constraint propagation

*Michael Kümmling, Jens Oplitz, Peter Großmann*

Usually, timetable optimization follows a simple route-wise traffic assignment based on ideal assumptions of conveyance times and interchange times. The feedback of the optimized timetable on the traffic assignment is ignored or modelled iteratively, leading to the amplification of the first found solution and potentially unexplored solutions. We apply techniques like constraint propagation to deduct general, but as close as possible, information on conveyance and interchange times from the timetable. This allows for the reduction of reasonable itineraries in a multi path traffic assignment. A set of rules especially fitted to railway journeys reduces the search space further. Using the determined multiple paths, a cyclic timetable optimization is conducted, based on the periodic event scheduling problem. First computational results are presented.

## ■ FA-20

*Friday, 9:00-10:30 - Seminarraum 404*

### Railway Applications (i)

Stream: Traffic and Passenger Transportation

Chair: *Ambra Toletti*

## 1 - A Column Generation Approach to Multi-Period Railway Rolling Stock Assignment

Susumu Morito, Jun Imaizumi, Motoki Miura, Takayuki Shiina

Railway companies construct daily schedules of assigning rolling stocks to utilization paths. A utilization path consists of a series of trains that a particular rolling stock performs in a day. The multi-period rolling stock assignment problem is modeled as a network flow problem in which nodes correspond to utilization paths of each day in the planning horizon, and a flow from a dummy source to a dummy sink is sought so that the arriving station of a utilization path coincides with the departing station of a utilization path. The model can be expressed as an integer program in which variables correspond to assignment of rolling stocks to a series of utilization paths in the planning horizon. Constraints require that each utilization path is always assigned to a rolling stock, and that each rolling stock selects a particular series of utilization paths for the planning horizon. A column generation algorithm is developed to the above integer program, but it was found that the solvable length of the planning horizon was 5 to 7 days and inappropriate assignment schedules were generated due to end effects. We show that the model can be modified to alleviate these difficulties, and also that the repeated applications of the optimization model in the rolling horizon allow to generate a feasible assignment for a longer period of time, thus indicating the feasibility of the optimization approach. The modifications of the model is based on the idea of relaxing the constraints that each utilization path is assigned to a single rolling stock except for the immediate future, thus leading to a mixed set covering/set partitioning formulation as opposed to the pure set covering formulation. Results of computational experiments are given based on the real data.

## 2 - Freight Train Routing and Scheduling in a Large Railway Network

Shripad Salsingkar, Narayan Rangaraj

As the need for railway transport is increasing, existing infrastructure capacity is getting saturated. Available capacity of railway network depends on infrastructure, traffic mix, volume, heterogeneity, speed, direction, etc. Many of the traffic related factors which impact available capacity can be controlled by effective routing and scheduling of trains.

Freight trains are planned closer to service execution, have less strict departure, arrival time windows and no fixed route to follow. Flexible routes of freight trains also offer operational flexibility. Effective routing and scheduling of freight trains in the network can achieve balanced network, lower delays, better capacity utilization, and higher throughput

Given a railway network with pre-scheduled passenger trains and a set of freight trains with origin and destination, the problem of finding a feasible route and schedule for each freight train without disturbing the passenger train schedule is defined as Freight Train Routing and Scheduling Problem (FTRSP). The objective is to minimize total time spent by the freight train in the network. The problem involves three decisions, namely, i) Routing, ii) Releasing and iii) Scheduling of trains in the railway network.

In this paper we present a methodology to solve FTRSP and its application to a sub-network of Indian Railways. We partitioned FTRSP into two sub-problems, i) Routing and Releasing and ii) Scheduling and solved these problems in sequence. We modeled 'Routing and Releasing' as a time indexed multi-commodity flow model. We used a priority based travel advanced greedy heuristics to schedule the trains. We present experimental results on the performance of this approach under different complexity level and report the findings.

## 3 - A resource conflict graph for energy efficient rescheduling of rail traffic

Ambra Toletti

Growing environmental awareness has pushed politics, industry and common citizens to promise and (sometimes) implement measures to reduce pollution and energy consumption. Rail transport has often found a place among these measures, as large quantities of goods and passengers can be moved with relative low energy costs if compared to private motorized transport.

Since the energy needed for building and maintaining railroads is very high, rail infrastructure has to be used very intensively to obtain low energy costs per passenger/ton. Unfortunately, the denser the traffic, the lower the operational stability. In fact, dense traffic means reduced buffer times between trains, and small perturbations may spread very quickly through the network and result in delays and even in unplanned

stops, which cause large energy losses. Industry has already started implementing solutions to energy saving (e.g. via speed advices) and to conflict resolution at junctions. At the same time, new methods to speed profile optimization and optimized conflict resolution have resulted from academic works. Few approaches combine energy saving and conflict resolution, and they usually face the two issues during different and disjoint steps of iterative or hierarchical processes.

In this work, a unique optimization instance faces both issues. The model is a Resource Conflict Graph, based on conflict avoidance according to the blocking time theory, and its input parameters (including energy consumption data) are obtained via off-line simulations, which reduces the on-line computational effort considerably. Experiments on simulated disturbed operations have shown that this approach allows to save large amounts of energy with respect to non-optimized and delay-oriented conflict resolution.

## ■ FA-21

Friday, 9:00-10:30 - Seminarraum 405/406

## Heuristic Vehicle Routing

Stream: Logistics, Routing and Location Planning

Chair: Martin Scheffler

### 1 - Split Methods for the Clustered Team Orienteering Problem

Ala Eddine Yahiaoui, Aziz Moukrim, Mehdi Serairi

The Clustered Orienteering Problem (COP) is a variant of the Orienteering Problem (OP) where customers are divided into groups called clusters with the possibility to have customers present in more than one cluster. A profit is associated with each cluster and is gained only if all customers of the cluster are served. We present in this paper a generalization of the COP called the Clustered Team Orienteering Problem (CluTOP) by introducing a fleet of identical vehicles. In this problem, customers of the same cluster can be served by different vehicles and a vehicle can visit customers from several clusters with no constraints on the order of visits. Our contribution is based on the route first-cluster second approach. The routing or ordering step, which consists of generating a predefined order/a sequence of visits on the clients, is generally handled by a meta-heuristic framework. In our case we choose a memetic algorithm with an adapted version of the Iterative Construction/Destruction Heuristic (IDCH) as a local search procedure. On the other hand, the clustering or splitting step consists of selecting a subset of clients to be visited based on a given sequence. The objective is to maximize the profit while respecting the distance constraint. To handle this phase, we propose heuristic split algorithm based on branch-and-bound scheme. We present also a second method based on ILP formulation with suitable relaxations to accelerate the resolution. We present a comparative study between the different splitting methods based on benchmarks from the literature with discussions about the results.

### 2 - Splitting procedure of genetic algorithm for column generation to solve a Vehicle Routing Problem

Martin Scheffler, Christina Hermann, Mathias Kasper

This paper considers a Vehicle Routing Problem with Simultaneous Pickup and Delivery and Time Windows (VRPSPDTW) extended by two kinds of demands assigned to specific nodes, introduced by Liu et al. (2013). As a practical application home health care logistics can be mentioned. The first demand concerns delivery from specific node one, e.g. a drugstore to customers and the second concerns pickup from customers to specific node two, e.g. a lab. Given the difficulty of this problem as NP-hard the use of metaheuristics for its solution is recommended. There is an abundance of studies about tuning common heuristics and using them for similar problems without a detailed view on the utilization of the generated informations. Therefore, this paper describes a relatively simple but effective extension of a genetic algorithm (GA) based on permutation chromosome and a splitting procedure. Using the splitting procedure to create a complete memory of all valid trips as feasible columns enables us to solve the master problem of a set partitioning formulation. The memory contains all feasible columns generated by the splitting procedure regardless of the offspring admissibility and the iteration productivity. The result is a hybrid metaheuristic with parallel search for a feasible solution (trip schedule for each vehicle) and integrated column generation. In a first step, a suitable frequency of solving the master problem is determined. Since it still is a heuristic the quality is evaluated in comparison to the

optimal solution identified by CPLEX for small instances. For large instances it is obvious to use the original GA as benchmark. These approaches are tested on test instances for the considered problem and by adjusted input data on classic VRPTW instances.

## Friday, 11:00-11:45

### ■ FB-02

Friday, 11:00-11:45 - Hörsaal 1

#### Semi-Plenary Klein

Stream: Semi-Plenaries

Chair: *Natalia Kliewer*

##### 1 - Revenue Management: Selected Concepts and Applications

*Robert Klein*

During the last three decades, Revenue Management has evolved into one of the most important fields of application of Operations Research. Basically, it is concerned with the task of optimally selling a fixed capacity of perishable resources within a given booking horizon, thereby maximizing the overall profit or contribution. This is essentially achieved by the application of two instruments: In a first step, \*price differentiation\* is performed, leading to a variety of differently priced products defined on the set of available resources. In a second step, the availability of these products is permanently adjusted by means of \*capacity control\* according to the current forecast of future demand. Beyond generating theoretical results concerning methods for capacity control, new concepts for modeling demand have been introduced recently and new application areas are emerging. To reflect these developments, this talk provides an overview on all three topics. Examples from well-known application areas like the airline industry, but also from recent ones like e-fulfillment are discussed.

### ■ FB-03

Friday, 11:00-11:45 - Hörsaal 2

#### Semi-Plenary Schultz

Stream: Semi-Plenaries

Chair: *Georg Pflug*

##### 1 - Stochastic Programs in Gas and Power Networks

*Rüdiger Schultz*

Up to fairly recently, power and gas suppliers have been at the sunny side, both technologically and politically. Due to market regulation, the economic actions of these companies were taken almost "with complete information" under granted sales prices. Some uncertainty remained regarding power and gas demand. But this comes close to nothing when looking at it from today's perspective: Deregulation led to unbundling of activities and, as a consequence, unbundling of knowledge on data. While before minimization of fuel costs for gas compression clearly dominated other expenses, it is the slogan of today to deliver gas to the right place at the right time in the right quantity, and with the right quality. Mathematical models facing these new developments will provide the guidelines for this lecture. A particular role will be taken by mild nonlinearities and their handling with both techniques from polynomial algebra and analysis.

### ■ FB-06

Friday, 11:00-11:45 - Hörsaal 5

#### Semi-Plenary Sörensen

Stream: Semi-Plenaries

Chair: *Stefan Voss*

##### 1 - A history of metaheuristics

*Kenneth Sörensen*

Even though people have used heuristics throughout history, and the human brain is equipped with a formidable heuristic engine to solve an enormous array of challenging optimization problems, the

study of heuristics (and by extension metaheuristics) is a relatively young endeavour. It is not an exaggeration to claim that the field of (meta)heuristics, especially compared to other fields of study like physics, chemistry, and mathematics, has yet to reach a mature state. Nevertheless, enormous progress has been made since the first metaheuristics concepts were established. In this talk, we will attempt to describe the historical developments this field of study has gone through since its earliest days. Taking a bird's eye view of the field of metaheuristics, one has to conclude that there has been a large amount of progressive insight over the years. Moreover, this progressive insight has not reached its end point: the way researchers and practitioners look at metaheuristics is still continually shifting. In our view, it is this shifting paradigm that deserves attention, as it allows us to truly understand the past and perhaps learn a few lessons that could be useful for the future development of research in metaheuristics. No history is ever completely neutral. We therefore do not attempt to hide the fact that certain ways in which the field has been progressing seem less useful, and sometimes even harmful to the development of the field in general. It is our conviction that the metaheuristics community itself is, at least partially, to blame for this. We will therefore also touch on some ways in which more scientific hygiene can be introduced in metaheuristics research. Nevertheless, a preliminary conclusion is that the field of metaheuristics has been steadily progressing towards becoming a mature field of research, and will continue to do so in the foreseeable future.

## Friday, 11:45-13:15

### ■ FC-02

Friday, 11:45-13:15 - Hörsaal 1

## Two-dimensional Packing Problems

Stream: Discrete and Integer Optimization

Chair: *Isabel Friedow*

### 1 - New lower bound based on relaxed model for the two-dimensional Variable Sized Bin Packing Problem

*Mohamed Maiza, Billal Merhoum, Mohammed Bouziane*

The variable sized bin-packing problem (VSBPP) is a natural extension of the well-known bin-packing problem (BPP) where the aim is to find the minimal possible cost generated by the use of heterogeneous bins required within a supply chain to store given items. This variant of problem arises in many practical applications such as cutting-stock problems, loading truck problems, assignment of process to processors, machine and telecommunication scheduling. In the addressed problem we consider several categories of identical bins, each bin category is characterized by the length, the width and the using cost. We consider also that expensive bins are those with a large surface. In this study, we propose a mathematical model that used to identify a new lower cost bound. The principle of the proposed lower bound is based on the relaxation of some constraints of the mathematical model. Solving both initial and relaxed mathematical models using CPLEX solver for different instances with up 250 items shows that the solution obtained by the relaxed model is close to the optimal. Our proposition presents an interesting trade-off between computation time and accuracy. Hence, for large instances, the relaxed model allows finding pseudo-optimal solutions within reasonable time.

### 2 - Creating Worst-Case Instances for Lower Bounds of the Two-Dimensional Strip Packing Problem

*Torsten Buchwald, Guntram Scheithauer*

We present a new approach to create instances with high absolute worst-case performance ratio of common lower bounds for the two-dimensional rectangular Strip Packing Problem. The idea of this new approach is to optimize the length and the width of all items regarding the absolute worst case performance ratio of the lower bound. Therefore, we model the pattern related to the lower bound as a solution of an ILP problem and merge this model with the Padberg-model of the two-dimensional Strip Packing Problem. The merged model maximizes the absolute worst-case performance ratio of the lower bound. We introduce this new model for the horizontal bar relaxation and the horizontal contiguous bar relaxation.

### 3 - An exact approach for the 2D rectangular strip packing problem

*Isabel Friedow*

We consider the 2D rectangular strip packing problem (SPP) which consists in packing a set of rectangles into a strip of fixed width and unrestricted height with the objective to minimize the strip height needed. In our case rotation of rectangles is not allowed. We investigate an exact approach based on the horizontal bar relaxation (HBR), in which a rectangle is represented by a unit-height item-type with demand corresponding to the rectangle height. The items are packed into one-dimensional bins and the aim is to minimize the number of bins used to meet demand of all items. Which items are placed in one bin is represented by a one-dimensional pattern. That continuous linear problem is solved by column generation. A stronger relaxation of the SPP is provided by the contiguous bin packing problem, in which all items of one item-type have to be placed in consecutive bins. Thus, we try to generate a set of consecutive patterns, called sequence, that contains all items. For that purpose, we add constraints to the master (HBR) which ensure that if a pattern, belonging to a sequence, is used in the solution all predecessors and at least one follower are used too. In the slave, we generate continuing patterns that are 2D-feasible, which means that every set of contiguous patterns represents a feasible partial 2D packing. To reduce the number of variables and constraints, we exclude sequences depending on lower bounds and sequences that represent identically shaped partial 2D packings. During the cutting plane approach we compute sequence depending upper bounds to obtain a strong upper bound for the SPP. Numerical experiments show that our approach is competitive with other exact methods proposed in literature.

## ■ FC-03

Friday, 11:45-13:15 - Hörsaal 2

### Environmental Aspects of Electric Mobility

Stream: Energy and Environment

Chair: *Patrick Jochem*

#### 1 - Analyzing Policies for E-Mobility Services with Renewable Energy

*Stephan Meisel, Tanja Merfeld*

We analyze an innovative business model in which an operator of a renewable energy system provides an e-mobility service to customers. The operator is equipped with a source of renewable energy, an energy storage device, and a fleet of electric vehicles. The vehicles are used for offering a car-sharing service as well as for providing additional storage capacity while on-site. We propose and analyze policies that allow the operator to make decisions about the use of energy at each point in time while operating the system. The operator's goal is maximization of profits from both car sharing and trading energy at the market. We formulate the resulting dynamic decision problem as a Markov Decision Process and compare two alternative types of policies for solving the problem: Lookahead policies as well as a policy function approximations. Our computational results show how the operator's preferred policy depends on problem characteristics such as the per km fee charged to car-sharing customers.

#### 2 - Stochastic bidding of electric vehicles at different energy markets

*Maren Kier, Christof Weber*

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

#### 3 - Locating fast-charging stations along the German Autobahn

*Patrick Jochem, Melanie Reuter-Oppermann, Stefan Nickel, Wolf Fichtner*

The roll-out of charging stations was seen as a necessary requirement for a successful market uptake of electric vehicles (EV). For long-distance trips, time is scarce, and therefore Mode 4 DC fast charging stations are currently high on the political agenda in Europe. The roll-out of the fast charging system is a severe investment for the future mobility system with EV and their optimal allocation is of high value for the society. The allocation of the first charging stations influences the profitability of all other fast charging stations and should therefore be perfectly arranged. In this talk we focus on the allocation of fast charging stations along the German Autobahn. In order to estimate the adequate number of charging points per fast charging location along the Autobahn in Southern Germany with respect to costs and waiting time of EV users, we first analyzed the workload of long distance trips over time in Germany. The data is taken from the most recent dataset "Mobilität in Deutschland". It is based on a survey in 2008 and 2009 on traffic information of over 100,000 people on the national

level. Together with disaggregated traffic flow data for each intercept, the specific flows between each highway exit are estimated. We use a flow-refueling coverage model for the optimized allocation of charging stations and include future developments and possible scenarios, for example for the market penetration, costs and range of EV. A simulation is used to study the waiting times and utilization depending on the size of the charging stations and to test the influence of different charging behaviors (e.g. early charging due to range anxiety or longer charging times). Resulting cost estimates and average distances to the electricity grid are given, too.

## ■ FC-04

Friday, 11:45-13:15 - Hörsaal 3

### Energy Storages

Stream: Energy and Environment

Chair: *Hannes Hobbie*

#### 1 - A Two-Stage Heuristic Procedure for Solving the Long-Term Unit Commitment Problem with Pumped Storages and its Application to the German Electricity Market

*Alexander Franz, Jürgen Zimmermann*

Today's highly volatile and stochastic characteristic of prioritized renewable feed-in and residual demand result in major challenges for operators and planners in the German and more and more in the European electric power system. The emerging need for highly flexible, but cost-efficient power plant operations can be supported by (pumped) storages and their ability to flatten the residual demand for remaining plant activities. Scheduling and coordinating power plants and storages lead to the NP-hard Unit Commitment Problem with hydro-thermal coordination (UCP-HT). In order to substantially reduce the computational burden of the underlying MILP, we present a two-stage heuristic procedure. At the first stage, plant activities are preselected to fulfill the ever-changing residual demand as well as spinning reserve requirements without any storage activities. Moreover, typical techno-economic parameters like power output specifications, minimum up/down-times, and time-dependent startups are included. Hereby, start solutions obtained by a multi-start greedy algorithm are repaired and enhanced by rule-based algorithms and local optimization routines. The second stage improves the solutions in consideration of energy storages. The best storage allocation is found by local adjustments of previous solutions replacing committed plant activities stepwise by storage operations to achieve further cost reductions. The final solution consists of a near-optimal hourly dispatch of each thermal and storage unit for, e.g., a yearly time horizon. Within a comprehensive performance analysis, we compare our approach to standard techniques using large-scale instances derived from the literature as well as a real-world case study of the electricity market in Germany.

#### 2 - Optimal temporal usage of salt cavern storage units for alternative media in light of intermittent renewables and carbon sequestration

*Xavier de Graaf, Reinhard Madlener*

Intermittent electricity production due to increasing shares of renewable energies, carbon capture and storage (CCS) technologies to mitigate climate change, and the increasing usage of hydrogen for transportation applications have one aspect in common: All three need long-term and large-scale storage facilities. Therefore, future competition for the most cost-efficient storage sites and usage types is likely. In our study, we propose an economic storage model which enables the user to identify the most economic utilization of a specific salt cavern storage site. Salt caverns represent the most flexible large-scale geological storage facilities today, presently mainly used for seasonal gas storage, and in Europe the potential for additional cavern storage use is high. Our model takes the technical properties of salt caverns as storage facilities into account, and allows for hydrogen, compressed air, methane and carbon dioxide as storage media. Real options analysis is used to value the stored medium during the lifetime of the cavern storage. Based on the expected market development, the model suggests the most attractive storage medium to maximize total profits. Potential storage costs for each application are compared with economic gains including cost savings (e.g. revenues from peak-load sale of electricity, avoided carbon tax) generated by an optimal time-dependent usage of the stored medium. The simulation results show that the estimated



storage costs for both the natural gas storage and the compressed air energy storage (CAES) unit exceed the discounted revenues in the base variant. Moreover, the value of intertemporal arbitrage of carbon dioxide is found to be insufficient to cover the marginal costs.

## ■ FC-05

Friday, 11:45-13:15 - Hörsaal 4

### Equilibrium Computation (i)

Stream: Game Theory and Experimental Economics

Chair: *Martin Hoefler*

#### 1 - Improved Balanced Flow Computation and Experiments on Combinatorial Algorithms for Linear Arrow-Debreu Markets

*Omar Darwish*

We present a new algorithm for computing balanced flows in equality networks arising in market equilibrium computations. The current best time bound for computing balanced flows in such networks requires  $O(n)$  maxflow computations, where  $n$  is the number of nodes in the network [Devanur et al. 2008]. Our algorithm requires only a single parametric flow computation. The best algorithm for computing parametric flows [Gallo et al. 1989] is only by a logarithmic factor slower than the best algorithms for computing maxflows. Hence, the running time of the algorithms in [Devanur et al. 2008] and [Duan and Mehlhorn 2015] for computing market equilibria in linear Fisher and Arrow-Debreu markets improve by almost a factor of  $n$ . Additionally, we report on some preliminary results and improvements discovered in our recent and ongoing implementation efforts of the combinatorial algorithms by Duan, Garg, and Mehlhorn for the linear Arrow-Debreu market model. Our observations on random instances show interesting behavior beyond what is predicted by the theoretical analysis of the running time and convergence properties. This is joint work with Kurt Mehlhorn.

#### 2 - Amortized Analysis of Asynchronous Coordinate Descent and Tatonnement

*Yun Kuen Cheung*

This paper concerns asynchrony in iterative processes, focusing on gradient descent and tatonnement, a fundamental price dynamic.

Gradient descent is an important class of iterative algorithms for minimizing convex functions. Classically, gradient descent has been a sequential and synchronous process, although distributed and asynchronous variants have been studied since the 1980s. Coordinate descent is a commonly studied version of gradient descent. In this paper, we focus on asynchronous coordinate descent on convex functions  $F: \mathbb{R}^n \rightarrow \mathbb{R}$  of the form  $F(p) = f(p) + \sum_{k=1}^n \Psi_k(p_k)$ , where  $f: \mathbb{R}^n \rightarrow \mathbb{R}$  is a smooth convex function, and each  $\Psi_k: \mathbb{R} \rightarrow \mathbb{R}$  is a univariate and possibly non-smooth convex function. Such functions occur in many data analysis and machine learning problems.

We consider a fairly general way to formulate asynchronous coordinate descent (ACD); it captures the standard synchronous coordinate descent, cyclic coordinate descent, and the version of stochastic coordinate descent that uses no-replacement sampling, a version which has not previously been analysed although it is used in practice.

We analyze this ACD process via an amortized analysis, the first such analysis for ACD. The bounds we obtain are worst case, even for stochastic coordinate descent! The amortization allows for bad updates (updates that increase the convex function value); in contrast, many prior works made the strong assumption that every update must be significantly improving.

We extend the analysis to show that an asynchronous version of tatonnement, a fundamental price dynamic widely studied in general equilibrium theory, converges toward a market equilibrium for Fisher markets with CES utilities or Leontief utilities.

This is joint work with Richard Cole (NYU).

#### 3 - Efficient Algorithms for Unknown Markets

*Martin Hoefler*

The talk surveys some of our recent work on revealed preference problems in classic market models without information about the number of agents, their individual utilities and endowments. Here we only rely

on queries that return aggregate demand for goods in order to, e.g., learn utility functions or compute a market equilibrium.

As a main result, we design a simple ascending-price algorithm to compute a  $(1+\epsilon)$ -approx. equilibrium in exchange markets with weak gross substitute (WGS) property. It runs in time polynomial in market parameters and  $\log(1/\epsilon)$ . Moreover, we show how to broaden our approach to markets with spending-constraint and budget-additive utilities, for which we obtain the first efficient algorithms to compute exact equilibria.

This is joint work with Xiaohui Bei and Jugal Garg.

## ■ FC-06

Friday, 11:45-13:15 - Hörsaal 5

### Innovative Applications in Pricing and Revenue Management

Stream: Pricing and Revenue Management

Chair: *Catherine Cleophas*

#### 1 - Cruise Line Revenue Management: Overview and Research Opportunities

*Daniel Sturm, Kathrin Fischer*

Cruise lines constitute an important and continuously growing sector of the worldwide leisure industry. With respect to revenue management, they share a variety of relevant attributes with airlines, hotels and especially casinos. However, revenue management practices and corresponding decision support systems which are suitable for other sectors of the leisure industry have to be adapted or extended in order to meet all requirements of cruise lines. Not only has a specific customer market segmentation to be applied, but also multiple capacity limitations have to be considered simultaneously. Additionally, individual customer values due to substantial on-board spending and individual customer choice behaviour patterns have to be incorporated into the revenue management process. Until now, decision support systems, optimization models, as well as pricing and allocation policies for cruise line revenue management have attracted little attention in the field of operations research. Based on a thorough review of the existing literature and by comparing it with revenue management models and practices in other areas, research gaps in cruise line revenue management are identified and possible approaches to close these gaps are discussed. These approaches include the extension of existing optimization models, the adaptation of known revenue management policies, the verification of their effectiveness using appropriate simulations, as well as the validation of their practical applicability based on scenarios derived from real world data sets.

#### 2 - Integer Linear Programming (ILP) Models for Price Recommendation for Online Retailers

*Somnath Sikdar, Ralf Winkler, Berkan Erol, Maximilian Werk*

We describe how one might use ILP models to recommend prices for online retailers with warehouses when there are multiple optimisation targets and where one is able to forecast the effect of prices for each article in the inventory. We consider the following scenario: customers buy articles online and are allowed to return them within a specified time window. The cost associated with an article has three components: a base cost (what the company pays to purchase the article); a fulfillment cost (the cost of storing the article in a warehouse and then delivering it to the customer); a return cost (the cost of sending the article back from the customer to a warehouse). We assume that we have a forecasting module that given future prices of an article for the entire duration for which it will be sold, predicts how many will be sold and how many will be returned per week for the said duration. The design of such a forecasting module is of independent interest but we only provide a brief description of it in this paper due to space reasons. In such a situation, we show how one might construct ILP models that recommend prices under a variety of optimisation criteria: maximising profits, maximising the number of sold articles whilst respecting budgetary constraints, minimising the loss whilst achieving a certain number of sold items. The last two cases are useful for special sales offers such as mid-season or end-of-season sales, or targeted advertising campaigns. Often these optimisation objectives have interesting applications not related to pricing. We give an example where the warehouse outbound traffic is regulated by adjusting discounts whilst minimising the loss in profits.

## ■ FC-07

Friday, 11:45-13:15 - Hörsaal 6

### Networks and Flows

Stream: Graphs and Networks

Chair: *Miriam Schlöter*

#### 1 - Analyzing the vulnerabilities of the German high-speed train network using quantitative graph theory

*Zhonglin Wang, Martin Zsifkovits, Stefan Wolfgang Pickl*

The German high-speed train system (ICE) as one of the critical infrastructures is mapped into a distance-weighted undirected network. The aim of the analysis is to make full use of quantitative graph theory in order to analyze the vulnerabilities of the network and to detect the centers and hubs of the system. When conducting network analysis of railways, traditionally the betweenness centrality measure and the efficiency measure are applied. Based on these two measures, a new vulnerability measure that we call betweenness-efficiency vulnerability measure is proposed, which can be used to detect the most vulnerable nodes. By analyzing and comparing the results of these three measures, highly vulnerable stations are identified, which therefore have more potential to harm the overall system in case of disruption. This can help decision-makers understanding the structure, behavior and vulnerabilities of the network more straightly from the quantitative graph theory's point of view. Based on the vulnerability index network residual closeness, we found the proposed new measure being more suitable than the traditional betweenness and efficiency measures. Finally, the problem of adapting a new vulnerability measure to this kind of system is discussed.

#### 2 - On the Convex Piecewise Linear Unsplittable Multi-commodity Flow Problem

*Bernard Fortz, Luís Gouveia, Martim Joyce-Moniz*

We consider the problem of finding the cheapest routing for a set of commodities over a directed graph, such that: i) each commodity flows through a single path, ii) the routing cost of each arc is given by a convex piecewise linear function of the load i.e. the total flow) traversing it. We propose a new mixed-integer programming formulation for this problem. This formulation gives a complete description of the associated polyhedron for the single commodity case, and produces very tight linear programming bounds for the multi-commodity case.

#### 3 - A new Way to solve the Quickest Transshipment Problem

*Miriam Schlöter, Martin Skutella*

Flows over time are a generalization of classical network flows. As they add a time component to the flows they are better suited for real world applications, for example evacuation. In an evacuation situation it is usually the aim to evacuate a number of people from an endangered area to certain safe sites with possibly bounded capacities as quickly as possible. This situation is modelled in the Quickest Transshipment Problem. Given a network  $N$  with capacities and transit times and a set of terminals with supplies or demands, a quickest transshipment is a flow over time in  $N$  satisfying all supplies and demands within minimal time. Hoppe and Tardos describe the only known polynomial time algorithm to solve this problem (1995). At first they determine the minimal feasible time horizon  $T$  for a given transshipment problem via one parametrized submodular function minimization. After that the actual transshipment needs to be computed. The main idea of the transshipment computation is to reduce it to a lexicographically maximum flow over time problem by attaching new sources and sinks to the network via arcs with suitable chosen capacities and transit times. However, for each attached terminal another parametrized submodular function minimization problem has to be solved. We describe a new way to solve a quickest transshipment problem which only requires the one submodular function minimization to determine the minimal feasible time horizon  $T$ . At first we show a structural result, namely that each quickest transshipment problem can be solved by a convex combination of at most number of terminals many lexicographically maximum flows over time. Then we show that a suitable convex combination can actually be computed while determining the minimal feasible time horizon  $T$ .

## ■ FC-08

Friday, 11:45-13:15 - Seminarraum 101/103

### Districting Problems in Business and Public Organizations (i)

Stream: Logistics, Routing and Location Planning

Chair: *Knut Haase*

#### 1 - Redistricting in Mexico

*Eric Alfredo Rincón-García, Sergio de-los-Cobos-Silva, Miguel Angel Gutierrez, Antonin Ponsich, Roman Anselmo Mora-Gutiérrez, Pedro Lara-velázquez*

Redistricting is the redrawing of the boundaries of legislative districts for electoral purposes in such a way that Federal or state requirements are fulfilled. In 2015 the National Electoral Institute of Mexico carried out the redistricting process of 15 states using a nonlinear programming model where population equality and compactness were considered as conflicting objective functions, whereas other criteria, such as contiguity, travel times between municipalities, and indigenous population were included as constraints. Besides, in order to find high quality redistricting plans in acceptable amounts of time, two automated redistricting algorithms were designed: a Simulated Annealing based algorithm, and, for the first time in Mexico, a population based technique was used, an Artificial Bee Colony inspired algorithm. The primary purpose of this presentation is to describe the main characteristics of this redistricting process. To address this issue, we provide a description of the problem, and a brief overview of the inner working mode of both optimization algorithms. Finally we include computational results that prove that the population based technique is more robust its counterpart for this kind of problems.

#### 2 - Toll zone planning for road-based traffic

*Martin Tschöke, Sven Müller, Sascha Ruja*

In light of the increasing attention on economic, environmental and health impacts of road traffic, methods for controlling its volume and density gain more and more importance. Especially legislators look into ways of letting users of road traffic contribute to covering infrastructure and maintenance cost. One important instrument in this respect is the introduction of toll collection systems and toll zones. In this paper, we introduce a new approach for planning toll zones that maximizes operational income. Overall revenue is determined on the basis of the total number of trips, number of toll zones passed and the price for passing a toll zone. As in tariff zone planning for public transportation, we further consider that users of road traffic are price sensitive and adapt their behavior with respect to the price structure of the system. We develop a MIP model that constructs consistent toll zones on the basis of a set of transitivity constraints. The model's applicability to real world cases is demonstrated by applying it to data from the San Francisco Bay Area using GAMS/ CPLEX. In addition to an analysis of model specific properties, the impact of the price-per-toll-zone on the total number of trips and on overall profit is examined.

#### 3 - Pilgrim camp layout planning for the annual Hajj operation of the Al-Mashaer Metro system

*Matthes Koch*

During the annual great Islamic pilgrimage, or Hajj, 2 - 5 million pilgrims gather at the holy sites of Makkah, Saudi-Arabia, to perform their religious duties. The rituals must be performed at specified locations and within specified time windows over the course of several days in order to complete Hajj successfully. The mass movement of the pilgrims is supported by a metro system, which transports about 400-500 thousand pilgrims between the holy sites. Because pilgrim travel group data varies from year to year, the layout of pilgrim camps is planned every year anew. Camp layouts for the pilgrim groups that use the metro system must respect requirements of crowd management as well as general logistic requirements like street-access, toilet-access, separation of nationalities and others. We propose a mathematical planning approach to solve this camp layout problem which can be easily coupled with our established approach to the pilgrim group timetabling problem for the metro system.

#### 4 - Revenue Maximizing Tariff Zone Planning

*Knut Haase, Sven Müller*

The counting zones tariff system is the prevailing system in metropolitan areas, such as London, Boston, and Perth. For the counting zones tariff system, the corresponding tariff is determined by the product of

the number of zones passed on the trip from origin to destination and the price per zone. In this paper, we contribute to the scant literature on public transport tariff zone design by a new model for the tariff zone design problem. The objective is to maximize the expected total revenue taking into account contiguous tariff zones and discrete fare levels. Demand as a function of tariff is measured as the number of public transport trips between origin and destination. For a given fare we compute the expected revenue for each origin-destination pair and the number of tariff zones passed. We present various MIP formulations yielding different zone patterns. Numerical examples based on artificial data are discussed.

## ■ FC-09

Friday, 11:45-13:15 - Seminarraum 105

### Preparedness in Civil Security and Humanitarian Aid

Stream: Security and Disaster Management

Chair: *Kathrin Fischer*

#### 1 - Prepositioning of Relief Items in Preparation for Disasters - Literature Overview and Realistic Case Study Design

*Emilia Grass, Kathrin Fischer, Antonia Rams*

Disaster-prone areas, as e.g. the American southeast coast, have to face the disastrous consequences of hurricanes every year. Preparation strategies can help significantly in reducing fatalities, economic damage and response times in the aftermath of a disaster. In particular, the prepositioning of relief items before the landfall of a hurricane may accelerate the adequate supply to those affected by the hurricane, and hence can decrease the number of casualties. Prepositioning issues have received much attention from the research community in recent years, resulting in an increased number of publications. While the focus of these papers is mainly on model presentation, efficient solution methods as well as realistic case studies are still lacking. Usually, only relatively small scale examples or case studies are chosen to ensure the solvability of the proposed model by means of commercial solvers. In addition, the lack of adequate data impedes the design of genuine examples. However, large scale problems of prepositioning relief items become more and more relevant for practical applications and more realistic examples have to be considered to validate methodological developments in realistic settings. After presenting a short overview on modeling approaches, an overview of application cases given in the state-of-the-art literature is provided, highlighting the gap to more realistic problems. Based on this review, a more realistic large-scale case study on prepositioning relief items in the Gulf of Mexico area is designed. As the development of appropriate solution methods for large-scale problems is another important issue in this regard, this aspect is emphasized in the contribution as well.

#### 2 - First Analytic System Dynamics Simulation Results for the Interplay of Airport Sectors

*Gonzalo Barbeito, Martin Zsifkovits, Michael Rampetsreiter, Martin Weiderer*

In 2001 security at airports became a very important topic. The recent terrorist attack on the Brussels airport showed that it did not lose any importance. Based on the quite probable assumption of a smart attacker, points with a high concentration of people need to be identified, as they will maximise the number of casualties. Due to the very different nature of the various sectors of an airport and their complex interplay, potential threats are hard to detect and predict analytically. In this paper we present first analytic simulation results with a system dynamics model, which focusses on a global risk management and shows the relevant sectors and their interconnection - keeping track of the number of people in each area as well. Even though the model is based on a generic airport, variation of the parameters allow for important conclusions to be drawn on bottlenecks, potential points of attack and possible counter measures.

## ■ FC-10

Friday, 11:45-13:15 - Seminarraum 108

### Applications of uncertain optimization

Stream: Optimization under Uncertainty

Chair: *Achim Koberstein*

#### 1 - Procurement Lot-Sizing Decision with Supplier Selection Under Discounts and Stochastic Lead Time

*Sunan Klinmalee, Thanakorn Naenna*

The suitable decision of procurement lot-size with supplier selection has potential to reduce the purchasing expenditures of a company. Like as the inventory management, it is one of the major activities in each organization. Therefore, the purchase planning and inventory control should be considered in accordance with the logistics of supplier and the market demand to increase the efficiency of the company in cost competition. In this paper, we develop a multi-product and multi-period inventory lot-sizing with supplier selection model for retail outlets. The minimization of total costs, which consist of ordering cost, holding cost, and purchasing cost, is the objective. We present the model under the discounts (all-unit and incremental quantity) and the stochastic lead time with an exponential distribution of the supplier. The safety stock is proposed to accommodate the uncertainty of supply while the demand for each product is known and dynamic over a planning. Additionally, the service level is defined as the probability that no shortage occur during a period of the planning. The proposed model is solved by a mixed-integer linear programming (MILP) approach to result in the optimal decision of procurement. Finally, numerical examples with sensitivity analysis, which involves the variation of problem parameters, are presented. The results obtained from this study specify what products to order in what quantities with which suppliers in which period to make the minimum total costs.

#### 2 - The Premarshalling Problem with Uncertain Pick-up Times

*Amelie Eilken*

In today's ports the storage area is often the bottleneck in the serving of a vessel. The workload of the yard varies significantly throughout the day with peaks during the serving time of a vessel or during rush hour times in truck arrivals. In modern block storage systems only the top container of a stack can be retrieved. Therefore if a container needs to be retrieved but is blocked by other containers standing on top of it (called a mis-overlay), these other containers need to be reshuffled first. In order to reduce the retrieval time per container during times with high workload, the containers of a block are rearranged in times with low workload such that the number of expected mis-overlays during peak times is reduced. In this premarshalling phase, a reshuffle schedule with a minimal number of reshuffle moves within a bay is sought such that the rearranged containers do not contain any mis-overlays. In this problem's common formulation the containers are numbered according to their retrieval times and have to be sorted accordingly. But in practice the exact pick-up times for containers are not known previously. Especially for the pick-up times for containers that leave via truck only time intervals are known. A new problem formulation is stated that aims to find a reshuffle schedule for the premarshalling phase such that a given confidence level can be guaranteed when only time windows and probability distributions are known. The objective remains the minimization of the number of necessary container moves. The problem's complexity as well as a mathematical model and first theoretical insights are presented.

#### 3 - Optimal operation and electricity sourcing in the aluminium industry

*Alessio Trivella, Stein-Erik Fleten, Denis Mazieres, Selvaprabu Nadarajah, David Pisinger*

An aluminium producer wishes to operate a smelter in a way that maximises value and minimizes shutdown risk. Electricity represents one of the major costs for the smelter and in this work we examine how the electricity procurement scheme may affect the shutdown risk. The problem is subject to multiple sources of uncertainty: electricity prices, aluminium prices and currency exchange rates, whose dynamics is captured using forward curves models. The operational flexibility for the smelter is given by i) operating full load, ii) mothballing for up to 3 years, or iii) closing down, with irreversible switching costs for shifting between modes. For a given set of electricity procurement contracts, an operating policy maximizing the smelter value can be found by solving a stochastic dynamic program with the least-squares Monte

Carlo method. On the other hand, the sourcing problem consists of a portfolio optimization problem of different short- and long-term electricity contracts, aimed at minimizing a trade-off between electricity cost and Conditional Value-at-Risk. In this work we formulate the joint stochastic optimization problem of smelter operations and electricity sourcing. The combined model is benchmarked against settings where the electricity demand from the smelter is assumed to be constant when sourcing, or where sourcing and smelter operations are solved in a sequential manner, i.e. an operating policy for the smelter is used as basis for electricity demand in the sourcing problem. The comparison highlights that, although the joint problem provides additional modelling and computational challenges, it might be important to integrate smelter operations and electricity sourcing, and an aluminium producer can reduce the risk without compromising the smelter value.

## ■ FC-11

Friday, 11:45-13:15 - Seminarraum 110

### Stochastic Models in Operations

Stream: Production and Operations Management

Chair: *Christoph Schwindt*

#### 1 - Markov model for system throughput analysis in warehouse design

*Anja Heßler, Christoph Schwindt*

When designing a warehouse, an important decision consists in dimensioning the storage and retrieval system appropriately, which presupposes an accurate model of the system throughput under steady-state conditions. The expected maximum system throughput equals the reciprocal of the expected operation cycle time, which for given storage location strategy and layout is largely influenced by the storage and retrieval strategy. This strategy defines the way in which storage locations are assigned to orders and the order set is partitioned into operation cycles. Disregarding the time savings achieved by optimally assigning storage locations to orders may heavily bias the throughput analysis. We consider a continuous-time Markov chain to derive analytical results for the expected operation cycle time under optimized storage and retrieval strategy. In a first setting, we consider a rack storage under random storage location strategy serviced by one rack feeder performing single command cycles. We assume homogeneous stock keeping units and storage and retrieval orders released according to independent Poisson arrivals. A system state is identified with the occupancy of the storage locations with stock keeping units. The optimized assignment of storage locations to the orders is taken into account by sorting the storage locations with respect to the resulting cycle times and only considering the first feasible location in this sequence for state transitions. An analytical formula for the expected cycle time results from constructing aggregate birth-death processes where for fixed parameter  $n$ , a system state is identified with the number of occupied storage locations among the first  $n$  locations.

#### 2 - Heuristic Approximations for Closed Networks: A Case Study in Open-pit Mining

*Ruslan Krenzler, Hans Daduna, Robert Ritter, Dietrich Stoyan*

We investigate a fundamental model from open-pit mining, which is a cyclic system consisting of a shovel, traveling loaded, unloading facility, and traveling back empty. The interaction of these subsystem determines the capacity of the shovel, which is the fundamental quantity of interest. To determine this capacity one needs the stationary probability that the shovel is idle. Because an exact analysis of the performance of the system is out of reach, besides of simulations there are various approximation algorithms proposed in the literature which stem from computer science and can be characterized as general purpose algorithms. We propose for solving the special problem under mining conditions an extremely simple algorithm. Comparison with several general purpose algorithms shows that for realistic situations the special algorithm outperforms the precision of the general purpose algorithms. This holds even if these general purpose candidates incorporate more details of the underlying models than our simple algorithm, which works on a strongly reduced model. The comparison and assessment is done with extensive simulations on a level of detail which the general purpose algorithms are able to cover.

#### 3 - Production Planning in Dairy Industry under Uncertainty

*Bilge Bilgen*

The dairy industry is a significant component of many economies, and is a major industry in the most developed and developing economies of the world. This study presents a novel mixed integer linear programming (MILP) model for the production planning of a multi-stage process within the dairy industry. The production process in the dairy industry consists of raw milk tanks, pasteurizers, processed milk tanks, sterilizers, aseptic tanks, and filling and packaging lines. Production stages are linked by intermediate storage tanks with limited capacities. This study has specifically focused on a number of industry specific characteristics (e.g. shelf life, intermediate storage, multi-stage processing, continuous flow, production bottlenecks, available connections, dedicated production lines, setup times, and costs). The key decision variables of this process are: the quantity of intermediate products, SKUs processed on resources in each time period, waiting times as raw milk and intermediate products on resources, quantity of SKUs sold; quantity of SKUs in inventory, lost sales of SKUs, and time consumed by resources. The objective is to maximize the total profits based on sales revenue from the products against the costs, such as setup, inventory holdings, lost sales, and production costs. Since one of the distinct characteristics of the dairy supply chain is uncertainty, the deterministic model is extended to deal with an uncertain demand parameter and risk management issues are discussed using an illustrative example.

## ■ FC-12

Friday, 11:45-13:15 - Seminarraum 202

### Combinatorial Optimization: New Approaches

Stream: Metaheuristics

Chair: *Silvia Schwarze*

#### 1 - Combinatorial Optimization via Weighted Superposition Attraction

*Adil Baykasoğlu, Mümin Emre Şenol*

Weighted Superposition Attraction (WSA) is a swarm based metaheuristic algorithm which is recently proposed for solving continuous optimization problems by the first author. Performance of the WSA was extensively tested with many unconstrained and constrained optimization test problems. Due to its competitive performance on continuous optimization problems we motivated to develop a combinatorial version of WSA in this research paper. A new approach is proposed to handle combinatorial problems without needing to use an indirect representation mechanism like random keys. Additionally, random walk mechanism along with opposition based learning is also incorporated into combinatoric WSA algorithm in order to further improve its diversification capability. The performance of the algorithm is tested on several resource constrained project scheduling problems. The preliminary results are promising; the best known solutions of many benchmark problems are improved.

#### 2 - A Sequential Hyperheuristic for Optimizing The Parameters of A Generic Parameterised Dual Local Search with a TSP Application

*Mona Hamid, Jamal Ouenniche*

Combinatorial optimization problems have been at the origin of the design of many optimal and heuristic solution frameworks such as branch-and-bound algorithms, branch-and-cut algorithms, classical local search methods, metaheuristics, and hyperheuristics. In this paper, we propose a sequential hyperheuristic to optimize the parameters of a generic and parametrised dual local search algorithm. We empirically assess the performance of the proposed framework using instances from the TSPLIB. Empirical results suggest that the proposed framework delivers outstanding performance.

#### 3 - An NSGA-III Approach for Multi-Objective Structural Optimization

*Amir H. Gandomi*

This study describes the Reference point based Non-dominated Sorting Genetic Algorithm-II (R-NSGA-II) called as NSGA-III for solving multi-objective challenging structural engineering problems that involve complex constraints. The reference point method is employed in the NSGA-III to store non-dominated Pareto optimal solutions obtained so far. Solutions are chosen based on the reference point mechanism which provides the best coverage of solutions in a multi-objective search space. To prove the effectiveness of the NSGA-III algorithm, first a set of standard unconstrained and constrained test functions are solved. The NSGA-III algorithm is then applied to a variety multi-objective structural design optimization problems, including truss design and beam design problems. The results are verified by comparing NSGA-III against other well-known multi-objective optimization algorithms such as NSGA-II and MOPSO. The results of the NSGA-III algorithm on the test functions shows that not only does the algorithm have high coverage, it also benefits from a quick convergence in compare with other algorithms. The results of the algorithms on the structural optimization problems demonstrate its applicability and a high potential to solve real-world and challenging problems.

## ■ FC-13

Friday, 11:45-13:15 - Seminarraum 204

### Optimal control for supply chain and operations management II

Stream: Control Theory and Continuous Optimization  
Chair: Gernot Tragler

#### 1 - Kuhn - Tucker optimality conditions in equilibrium optimization models for network industries markets

Michal Fendek, Eleonora Fendekova

Currently a significant attention in scholarly discussions on various levels is being paid to the subject of network industries. It is understandable as network industries in fact ensure the production and distribution of energy sources which play a key role in an effective operation of the developed economies. The discussions are usually focused on the question of a reasonable profit of the network industries companies and on the other hand on the question of prices which are determined by the reasonable and generally acceptable costs of their production. Naturally, equilibrium on the network industries market, as well as on any market, is being created based on the level of demand and supply on said market. For the network industries market equilibrium models a certain segregation of the market is characteristic, resulting in the network industries production usually not being substitutable. Therefore a satisfaction gained from their consumption can be uniquely quantified. In principle, it is such a representation of utility function where a network industry product is considered to be a good with its own and exactly formulated utility function and the other goods are considered as a consumption of one calculated aggregated good with standardized unit price. In this paper we will discuss the analysis of microeconomic optimization models of consumers and producers behavior on the network industries market, i.e. the analysis of demand and supply phenomena on this specific market, as well as the general questions of network industries sector effectivity. For the optimization problems we will formulate the Kuhn-Tucker optimality conditions and we will study their interpretation options.

#### 2 - Fluctuating supply and learning by doing in a non-autonomous optimal control model of renewable energy production

Gernot Tragler, Elke Moser, Dieter Grass

The world-wide energy demand is still increasing implying an increase in greenhouse gas emissions, so an urgent task is to find a carbon-low energy supply through an optimal trade-off between energy security and sustainability. Energy security, however, turns out to be difficult for renewable energy generation because the supply of renewable sources underlies strong volatility. We address this issue by means of a non-autonomous optimal control model determining the optimal mix of fossil and renewable energy used to cover the energy demand of a small country. We assume that the supply of the renewable resource fluctuates seasonally and also include learning effects for the renewable energy technology.

## ■ FC-14

Friday, 11:45-13:15 - Seminarraum 206

### Queueing Networks

Stream: Simulation and Stochastic Modeling  
Chair: Hans Daduna

#### 1 - Queueing networks with infinite supply : Local stabilization and local equilibrium analysis

Hans Daduna

We investigate queueing networks in which some nodes have an infinite supply of work. Whenever such nodes become empty they serve customers from the infinite supply on a low priority preemptive resume basis. Such nodes are fully utilized even if they stabilize over time. Our main interest is in describing the long time behaviour of the network if some of the nodes (with or without infinite supply) are unstable. This means that we have for the nodes a classification along the binary classifications stable-unstable and with-without infinite supply, which results especially in considering ergodic and non-ergodic network processes. We compute for any situation the flow rates, i.e. the solution of the modified traffic equations, and provide a rather complete picture of the possible limiting and stationary behaviour. Of special interest is that even for non-ergodic network processes we can prove theorems on local stabilization in the long run, respectively of the existence of local stationary distributions for parts of the network. These stationary respectively limiting local distributions on subnetworks are of product form as in the classical Jackson networks. But usually there is no such product form equilibrium or product form limiting distribution for the complete network process. This talk is on joint work with Jennifer Sommer and Bernd Heidergott.

#### 2 - Integrated models for production-inventory systems with base stock policy

Sonja Otten, Ruslan Krenzler, Hans Daduna

Production processes are usually investigated using models and methods from queueing theory. Control of warehouses and their optimization rely on models and methods from inventory theory. Both theories are fields of Operations Research (OR), but they comprise quite different methodologies and techniques. In classical OR these theories are considered as disjoint research areas. Today's emergence of complex supply chains (=production-inventory networks) calls for integrated production-inventory models, which are focus of our present research.

We consider a two-echelon production-inventory system with a supplier connected to parallel production systems (servers) at several locations, each with a local inventory. Demand of customers arrives at each production system according to a Poisson process and is lost if the local inventory is depleted. To satisfy a customer's demand each server needs exactly one unit of raw material from the associated local inventory. The supplier manufactures raw material to replenish the local inventories, which are controlled by a base stock policy, i.e. each unit taken from the associated local inventory results in a direct order sent to the supplier. The supplier can be of complex structure, e.g. a production network itself.

We develop a Markov process model for this production-inventory system and derive the steady state distribution of the system in explicit product form. This enables us to analyze the long term average costs with the aim to find the optimal base stock levels.

This model is an extension of the model introduced in Otten, Krenzler and Daduna (2015): Models for integrated production-inventory systems: steady state and cost analysis. International Journal of Production Research. doi:10.1080/00207543.2015.1082669.

#### 3 - Decomposition of open queueing networks with batch service

Wiebke Klünder

The decomposition method for non-product form networks with non-exponentially distributed interarrival and service times assumes that nodes within the network can be treated being stochastically independent and internal flows can be approximated by renewal processes. The method consists of three phases to calculate the interarrival times of a node: merging, flow, splitting. Some well-known approximation formula for ordinary single class open queueing networks calculate the characteristics in each phase for each node as shown by Kuehn, Chylla, Whitt and Pujolle/Ai. Node performance measures such as mean queue length are determined by using approximation formula for non-Markovian queues. 2011 the decomposition method was extended

to open queueing networks with batch processing using the approximation formula described by Pujolle/Ai. A comparison with discrete event simulation as benchmark shows that the approach provides good results. Thus, the approach was expanded for the approximation given by Kuehn, Chylla and Whitt. Since the method consists of several phases it is possible to combine different formula. For example merging will be approximated by Kuehn and flow by Whitt. To perform an evaluation the benchmark was done in regard to the 2011 publication. Approximation formula with the same approach generate similar results. In some cases it is apparent that some formula have advantages over other ones and a few tend to larger errors. Thus, the focus of interest particularly address the load and batch size changes within the network and the impact on the accuracy of the decomposition method as a fast solver or pre-evaluation for optimization using simulation.

## ■ FC-15

Friday, 11:45-13:15 - Seminarraum 305

### Scheduling with MIPs

Stream: Project Management and Scheduling

Chair: Franz Ehm

#### 1 - A multi-criteria MILP formulation for energy aware hybrid flow shop scheduling

Sven Schulz

The present paper introduces a multi-criteria parallel flow shop problem considering variable discrete production speeds. Managing energy consumption more sustainably and efficiently is one of the most significant challenges for a growing society in the twenty-first century. In recent years, consequently, the consideration of energy consumption has been gaining increasing importance in all industrial planning processes. Logically, there is also a limited set of papers dealing with different aspects of energy consumption as well as energy costs in scheduling. Overall, three different approaches can be identified. In detail, the energy consumption can be reduced by specific planning, time-dependent electricity cost might be exploited or the peak power may be decreased. In contrast to the majority of energy aware scheduling models these ideas are adopted simultaneously in the proposed new extensive MILP formulation. In order to affect peak load and energy consumption variable discrete production rates as well as heterogeneous parallel machines with different levels of efficiency are considered. As a result, the interdependencies of different energy aware scheduling approaches can be shown. Furthermore, a multi-criteria objective function is proposed. Besides total completion time, time depending energy costs and the peak power are minimized. It can be shown that there is a dilemma between peak power minimization and demand charge reduction. A compromise proposal is given for this contrary effect. Since this problem is NP-hard, the numeric example is not only solved by classical solver software but also by using a heuristic approach. The results of the numeric example illustrate how the model operates.

#### 2 - Lower bounds for the two-machine flow shop problem with time delays

Mohamed Amine Mkaem, Aziz Moukrim, Mehdi Serairi

We address the flow shop scheduling problem with two machines and time delays. We dispose of a set  $J=1,2,\dots,n$  of  $n$  jobs that must be executed without preemption on two machines  $M1$  and  $M2$ , which can only handle one operation at a time. Each job  $j$  has two operations. The first operation must be executed during  $p(1,j)$  time units on  $M1$ . Then,  $l_j$  time units are needed to transport job  $j$  to  $M2$ , where the second operation has to be executed during  $p(2,j)$  time units. The objective is to find a feasible schedule on the two machines that minimizes the completion time of the last scheduled job on  $M2$ . This problem is NP-hard in the strong sense even with unit-time operations.

We present a comprehensive theoretical analysis of the different lower bounds of the literature and we propose new relaxation schemes. Then, we elucidate dominance relationships between them. Moreover, we investigate a linear programming-based lower bound that includes the implementation of a new dominance rule and a valid inequality. Finally, we present the result of an extensive computational study that was carried out on a set of 480 instances including new hard instances. Our new relaxation schemes outperform the state of the art lower bounds.

### 3 - Machine scheduling for multi-product disassembly

Franz Ehm

In recent years, manufacturers of consumer goods have been faced with a substantial reflow of end-of-life products mainly due to increased ecological thinking among customers or legal directives. There are several strategies which have emerged under the topic of remanufacturing in order to exploit the remaining economic value from these products. The efficient disassembly plays a key role in enabling these potentials or limit the losses resulting from the duty of disposal. This study represents a novel approach to combine the problems of disassembly sequence planning and machine scheduling. In this context, we assume a shop of several non-identical stations which are available for the complete disassembly of a given set of heterogeneous products. The problem is to simultaneously determine the sequence of disassembly operations for each product and the order of products at the stations with the objective of minimizing makespan. The approach taken in this study presents some similarities to existing formulations in the field of job shop scheduling with alternative process plans. However, the proposed model explicitly considers divergence of the product structure as inherent feature of disassembly. That is, separate sub-assemblies of the same product may be disassembled at the same time meaning operations of the same job can possibly overlap in the schedule. Therefore, we derive a graph-based representation which incorporates both alternative and parallel operations for each product. A mixed-integer-program is then deployed to solve the combined problem using commercial optimization software. Finally, we provide a numerical study to analyze the effects on solution time and quality under varying problem configurations.

## ■ FC-16

Friday, 11:45-13:15 - Seminarraum 308

### Multi Machine Scheduling

Stream: Project Management and Scheduling

Chair: Klaus Jansen

#### 1 - ZDD and generic branching in branch-and-price algorithms for scheduling problems

Daniel Kowalczyk, Roel Leus

We tackle the parallel machine scheduling problem to minimize the total weighted completion time (WCT), which is known to be NP-hard. We use zero-suppressed binary decision diagrams (ZDDs) to solve the pricing problem in a branch-and-price (B&P) algorithm for a partition formulation of WCT that was introduced by van den Akker et al. (Operations Research, 1999). We show that a number of generic branching rules for B&P, e.g. the Ryan-Foster branching rule, can be used by adding constraints to the pricing problem instead of adding constraints to the variables of the partition formulation (the latter approach is followed, for instance, by Morrison et al. (INFORMS JOC, 2016) for vertex coloring).

#### 2 - Bounded dynamic programming algorithm for solving the job shop scheduling problem with sequence dependent setup times

Ansis Ozolins

In the current work, the job shop scheduling problem with sequence dependent setup times (SDST-JSS) is inspected. The goal is to minimize makespan, i.e. the completion time of the last job. The SDST-JSS as the generalization of the classical job shop scheduling problem is NP-hard therefore only few exact procedures are known in the literature. We propose new algorithm for solving SDST-JSS optimally based on the bounded dynamic programming approach. This method significantly differs from the classical branch and bound procedure since a domination relationship between different schedules is given. Computational results show that presented algorithm works on practice solving moderate benchmark instances.

#### 3 - Closing the Gap for Makespan Scheduling via Sparsification Techniques

Klaus Jansen, Kim-Manuel Klein, Jose Verschae

Makespan scheduling on identical machines is one of the most basic and fundamental packing problems studied in the discrete optimization literature. It asks for an assignment of  $n$  jobs to a set of  $m$  identical machines that minimizes the makespan. The problem is strongly

NP-hard, and thus we do not expect a  $(1+\epsilon)$ -approximation algorithm run on a time that depends polynomially on  $1/\epsilon$ . Furthermore, Chen et al. recently showed that a running time of  $2^{(1/\epsilon)n} \delta + \text{poly}(n)$  for any  $\delta > 0$  would imply that the Exponential Time Hypothesis (ETH) fails. A long sequence of algorithms have been developed that try to obtain low dependencies on  $1/\epsilon$ , the better of which achieves a running time of  $2^{\tilde{O}(1/\epsilon^2)} + O(n \log n)$ . In this paper we obtain an algorithm with a running time of  $2^{\tilde{O}(1/\epsilon)} + O(n \log n)$ , which is tight under ETH up to logarithmic factors on the exponent.

Our main technical contribution is a new structural result on the configuration-ILP. More precisely, we show the existence of a highly symmetric and sparse optimal solution, in which all but a constant number of machines are assigned a configuration with small support. This structure can then be exploited by integer programming techniques and enumeration. We believe that our structural result is of independent interest and should find applications to other settings. In particular, we show how the structure can be applied to the minimum makespan problem on related machines and to a larger class of objective functions on parallel machines. For all these cases we obtain an efficient PTAS with running time  $2^{\tilde{O}(1/\epsilon)} + \text{poly}(n)$ .

## ■ FC-17

Friday, 11:45-13:15 - Seminarraum 310

### Supply chain planning and lot-sizing

Stream: Supply Chain Management

Chair: Hartmut Stadler

#### 1 - Balancing Effort and Plan Quality: Tactical Supply Chain Planning in the Chemical Industry

Annika Vernbro, Iris Heckmann, Stefan Nickel

Tactical planning is a frequently recurring task, which typically involves data, automated planning procedures and manual planning efforts. The degree, to which planning can be automated does depend on the choice of method implemented in the automated procedure and on the validity of underlying data. Competent application of optimization techniques in this context usually requires specialized skills and method-related knowledge. However, planners might have a background in overseeing production or comparable functions and personnel with expertise in optimization is scarce.

Thus, in practice simple heuristic algorithms provided by an ERP-system might be chosen for implementation as automated planning procedure for Supply Network Planning. However, common simple heuristics do not even consider capacity constraints. This leads to considerable amounts of manual planning efforts. Still, for complex supply chains the resulting plans likely lack in quality. Available advanced heuristics on the other hand can produce better plans but at the same time require expertise and maintenance efforts comparable to optimization based approaches. We introduce a concept of quality of supply network plans and investigate the incorporation of certain dimensions of quality in application friendly planning heuristics. For an instance from chemical industry we evaluate approaches to incorporate basic constraints as well as plan quality requirements in a still simple heuristic planning procedure to achieve balance between effort and plan quality.

#### 2 - Multi-Stage Multi-Product Simultaneous Lot Sizing and Scheduling with Time Windows

Jonas Ostmeier

It is well-known that simultaneous lot sizing and scheduling is an important instrument in supply chain management. The most common models are based on the assumption of deterministic demand quantities which are given for a fixed point in time. Hence in such a framework there is no flexibility for satisfying this demand with respect to the delivery date. But obviously in real world applications the observed customer behaviour differs significantly from that situation. In fact, often the customer offers an earliest and a latest delivery date.

In this contribution we present a new model that incorporates the aforementioned idea of time windows. This adaption requires a decoupling of demand and delivery. All modifications result in a multi-stage multi-product simultaneous lot sizing and scheduling with capacity restrictions, setup carry overs, flexible production structures and time windows. Finally, a small numerical example demonstrates the overall benefit of the new approach.

### 3 - Lower Bounds for Capacitated Lot-Sizing with Stochastic Demand and Service Level Constraints

Hartmut Stadler, Malte Meistering

Recently, new approaches have been proposed in literature to model capacitated lot-sizing problems with stochastic demands given some service level constraints. In contrast to well-known stochastic or robust optimization approaches these new proposals do not require to model scenarios and thus have a much greater potential to be used for solving (large-scale) real world production planning problems.

However, lower bounds showing the potential optimality gap associated with these new approaches are still missing in literature. To close this gap we present deterministic model formulations for the capacitated lot-sizing problem (CLSP) including given service level constraints. We will consider the periodic and cyclic  $\alpha$ -service level as well as the  $\beta$ -,  $\gamma$ - and  $\delta$ -service level). Here, we assume that service levels for individual products are controlled over a given evaluation interval (e.g., one year).

Preliminary computational results will also be presented.

Key words: Capacitated lot-sizing, demand uncertainty, service levels, lower bounds

## ■ FC-18

Friday, 11:45-13:15 - Seminarraum 401/402

### Efficient Neighborhood Search for Vehicle Routing Problems

Stream: Logistics, Routing and Location Planning

Chair: Timo Gschwind

#### 1 - Large Neighborhood Search for the Clustered Vehicle Routing Problem

Timo Hintsch, Stefan Irnich

This presentation considers the Clustered Vehicle Routing Problem (CluVRP) which is a variant of the classical Capacitated Vehicle Routing Problem. Customers are partitioned into clusters and it is assumed that each cluster must have been served in total before the next cluster can be served. This decomposes the problem into three subproblems, the assignment of clusters to tours, the routing inside a cluster, and the routing of the clusters in the tour. The second task requires the solution of several Hamiltonian path problems, one for each possibility to start and end the route through the cluster. These Hamiltonian paths are pre-computed for every pair of customers inside each cluster. The chosen start-end-pair of the clusters also affects the routing of clusters. We present a Large Neighborhood Search which makes use of the Balas-Simonetti-neighborhood. Computational results are compared to existing exact and heuristic approaches from the literature. In addition a second variant, the CluVRP with soft constraints, is considered. Customers of same clusters must still be part of same routes, but do not need to be served contiguously any more. Adaptions of our approach are discussed.

#### 2 - An Adaptive Large Neighborhood Search for the Dial-a-Ride Problem

Timo Gschwind, Michael Drexler

In the Dial-a-Ride Problem (DARP), user-specified transportation requests from origin to destination points have to be serviced by a fleet of homogeneous vehicles. The problem variant we consider aims at finding a set of minimum-cost routes satisfying pairing and precedence, capacity, time-window, maximum route-duration, and maximum user ride-time constraints. We propose an adaptive large neighborhood search (ALNS) for its solution. The key novelty of the approach is an exact constant-time algorithm for evaluating the feasibility of request insertions in the repair steps of the ALNS. Computational results indicate that the basic version of our ALNS is competitive to state-of-the-art methods for the DARP regarding both solution quality and computation times. To increase the solution quality, we propose two optional improvement techniques: A local-search based, intra-route improvement of all routes of promising solutions using the Balas-Simonetti neighborhood and the solution of a set-partitioning model including all routes generated during the search. Using these techniques, the proposed algorithm outperforms the state-of-the-art methods in terms of solution quality. New best known solutions are found for several benchmark instances.

## ■ FC-19

Friday, 11:45-13:15 - Seminarraum 403

### Polyhedral and Heuristic Methods for Railway Timetabling

Stream: Traffic and Passenger Transportation  
Chair: *Andreas Börmann*

#### 1 - Rail rapid transit Timetabling Problem under dynamic passenger demand: Exact formulations

*David Canca, Eva Barrena, Gilbert Laporte, Leandro Coelho*

The Railway planning process is a complex activity that is usually decomposed into several stages, namely network design, line planning, timetabling, rolling stock, and crew rostering and scheduling. In this work we study the design and optimization of non-periodic train timetables when passengers demand follows a dynamic behavior along certain planning horizon. We present four different formulations for this problem. All of them try to minimize the passenger average waiting time. The first one consists of a mixed integer non-linear programming model in which binary variables represent train launching times and the objective function contains a quadratic term. The remaining ones incorporate flow variables, allowing for a linear representation of the objective function. We compare the benefits and disadvantages of each formulation and present a branch-and-cut algorithm applicable to all of them. Finally, we perform experiments derived from real data and show the advantages of designing a timetable adapted to the demand pattern, as opposed to a regular timetable.

#### 2 - Adaptive Large Neighborhood Search to solve the rail rapid transit timetabling under dynamic passenger demand

*Eva Barrena, David Canca, Gilbert Laporte, Leandro Coelho*

We analyze the problem of designing train timetables for a rail rapid transit (RRT) line subject to a dynamic passenger demand pattern with the objective of minimizing the average passenger waiting time at the stations. We discuss two mathematical programming formulations that generalize the non-periodic train timetabling problem on a single line when a dynamic demand pattern is considered. Since exact methods have their limitations to deal with real size instances, we consider the use of heuristics or metaheuristics. By analyzing the properties of the problem, we suggest a fast adaptive large neighborhood search (ALNS) metaheuristic in order to solve large instances of the problem within short computation times. A set of extensive computational experiments allows us to demonstrate the ALNS computational superiority in comparison with a truncated branch-and-cut algorithm. We have succeeded in reducing the passenger AWT by 26% by using less than 1% of the computation time required by the latter algorithm.

#### 3 - Compact Tight Optimization Models for Energy-Efficient Railway Timetables

*Andreas Börmann, Alexander Martin, Oskar Schneider*

In this talk, we present compact tight model formulations for the optimization of railway timetables. The goal is to minimize the energy costs of the railway operator which are incurred by high peaks in power-consumption by the circulating railway traffic. The models are validated on real-world instances by our industry partner Deutsche Bahn AG and show high potential for cost savings.

A large part of the energy cost of a railway operator does not depend on the total amount of energy used by the trains, but only on the temporal balancedness of the consumption. Thus, an evenly distributed power consumption over time is much cheaper than having high peaks and low valleys, according to the typical electricity contracts of big consumers. Our approach consists in adapting a tentative timetable by shifting the departure times of the trains by few minutes. This allows to desynchronize too many simultaneous departures causing high peaks in consumption and to make better use of the recuperated energy by braking trains at the same time. The aim is to minimize the maximal power consumption for a sample day of the planning period.

Our models take the form of mixed-binary problems of project scheduling type for which we present compact tight representations. We compare the results on a compatibility formulation with that of a potential-based formulation which both allow for a totally unimodular representation of the set of feasible timetables of polynomial size. To validate our models, we conduct a case study on real-world instances for regional and long-distance traffic from our industry partner

Deutsche Bahn AG. The results show that significant savings in energy costs are possible by using our approach.

## ■ FC-20

Friday, 11:45-13:15 - Seminarraum 404

### Advances in Railway Transportation (i)

Stream: Traffic and Passenger Transportation  
Chair: *Frank Fischer*

#### 1 - A Robust Approach to Integrating Energy Peak Loads in Operational Train Timetabling

*Anja Hähle, Christoph Helmberg*

Operational train timetabling asks for feasible schedules for trains that take into account time windows and prespecified routes as well as other constraints such as station capacities and headway times. Another significant factor is the overall energy consumption profile which mainly depends on when and how often trains accelerate. Indeed, within electricity costs the total energy consumption is just one contributor. The electricity bill also includes a significant component for the energy peak loads. Therefore the generation of energy-efficient train timetables is not only interesting from an environmental perspective but is also an important competitive factor for railway companies. We propose a model for including energy peak loads in train scheduling and present computational results on real world instances of Deutsche Bahn. Since energy peaks can be displaced by a variety of external influences and practical data are never completely certain, we discuss approaches to improve the robustness of the model by using robust optimization techniques.

#### 2 - An integrated service-network design and hub location problem for intermodal traffic

*Thorsten Ramsauer, Andreas Börmann, Alexander Martin*

In this talk we present a case study on a real-world integrated service-network design and hub location problem for intermodal road/rail-traffic. We consider a mixed-integer formulation which links three important decisions of bimodal traffic from an infrastructure and logistics provider's point of view and resolves them simultaneously. On the first level the model solves the infrastructure provider's hub location problem that is deciding where to build additional transshipment terminals. Since this decision depends on the structure of the transports usually performed in the network, the second decision is to determine the mode of transportation for each order in a given set of typical transport orders. Finally, to ensure efficient transportation, a railroad blocking problem needs to be solved for the orders picked for intermodal transportation. The overall objective is to minimize transportation costs and energy consumption. To solve this model we developed a bunch of preprocessing steps that are able to significantly shrink the problem size while maintaining the exactness of the approach. The remaining problem is then solved using a branch-and-bound algorithm. Computational studies with real-world data from a large railway-company in Germany show promising potential in cost and energy savings by shifting more traffic from road to rails.

#### 3 - A Re-optimization Approach for Train Dispatching

*Thorsten Klug, Frank Fischer, Thomas Schlechte, Boris Grimm*

The Train Dispatching Problem (TDP) is to schedule trains through a network in a cost optimal way. Due to disturbances during operation existing track allocations often have to be re-scheduled and integrated into the timetable. There are various causes that can lead to a situation where the implemented timetable becomes unexpectedly infeasible. Predictable and unpredictable construction sites and breakdowns that block a track must be integrated shortly into a timetable. In addition, delayed trains and modifications of speed limits may require an adjustment of the timetable. Since an operator has only minutes or seconds for his decisions, a re-optimization algorithm has to calculate solutions within a real time management system. Another major goal is to change as few as possible in comparison to the original timetable. This should minimize the disturbance of the ongoing timetable because fewer changes are easier to communicate, easier to apply, and hence more reliable. Moreover, changing a lot of routes and switching the orders of trains is very likely to result in an impractical timetable due to a significant amount of uncertainty. We present an integrated modelling approach for this kind of re-optimization tasks using Mixed Integer Programming. Finally, we provide computational results for



scenarios provided by the INFORMS RAS Problem Solving Competition 2012. The computational results indicate that the model and algorithmic approach produces high quality solutions in a very short time.

provide a greedy algorithm that provably finds the optimal allocation of docks (and bikes) in a fraction of the prior computation time. Our work is used by NYCBS beyond the allocation of docks, informing for example their redistribution of bikes.

## ■ FC-21

Friday, 11:45-13:15 - Seminarraum 405/406

### Facility Location and Capacity Problems

Stream: Logistics, Routing and Location Planning

Chair: *Daniel Freund*

#### 1 - Closest and barrier distances in the presence of a finite size facility

*Masashi Miyagawa*

This work develops a bi-objective model for determining the location, size, and shape of a finite size facility. The objectives are to minimize both the closest and barrier distances. The closest distance represents the accessibility of customers, whereas the barrier distance represents the interference to travelers. The distributions of the closest and barrier distances are derived for a rectangular facility in a rectangular city where the distance is measured as the rectilinear distance. The analytical expressions for the distributions demonstrate how the location, size, and shape of the facility affect the closest and barrier distances. A numerical example shows that there exists a tradeoff between the closest and barrier distances.

#### 2 - Min-max fair emergency system with randomly occupied centers

*Jaroslav Janacek, Marek Kvet*

The contribution is focused on min-max fair emergency service system design under uncertain center ability of service providing caused by current occupation of the center by previously raised demand. Studied generalized system disutility follows the idea that the individual user's disutility comes from more than one located service center and the contributions from relevant centers are weighted by some coefficients, which may express probability that the associated center is the nearest opened center from the located centers for the user. The main goal of this contribution is to present a fast approach to the min-max optimal emergency service system design. Within the paper, the generalized system disutility will be studied. The model of generalized disutility impacts the complexity of the problems, which must be solved by used solving techniques. The consequence of the generalized disutility model is that the suitability of common approaches considerably changes, when the min-max optimal emergency service system is designed. We introduce here an advanced approximate algorithm for the min-max location problem based on radial formulation and valid exposing structures. Furthermore, presented method enables its simple implementation within common optimization environment instead of the necessity of developing special software tool.

#### 3 - Allocating Capacity in Bikeshare-Systems

*Daniel Freund, Shane Henderson, David B. Shmoys*

Bikeshare-systems (BSSs) allow users to rent and return a bike at any station within the system. The last decade has witnessed not only a significant increase in the number of BSSs, but also a leap in the usage data these systems collect. We present data-driven methods to support New York City Bike Bikeshare's (NYCBS) operations. In particular, in this talk we extend a model to allocate docks within the system so as to minimize out-of-stock events (OOS). We model demand for bikes and docks at individual bikeshare-stations using continuous-time Markov chains. At each station, customers arrive (independently) with Poisson-rates to return or rent a bike. An out-of-stock event occurs when a customer arrives to rent (return) a bike when the station is empty (full). Past work has shown that with constant exogenous rates our cost-function, the expected number of OOS, can be computed exactly. Using a stochastic dynamic program, we show that this extends when rates are time-dependent. Moreover with constant rates the cost-function is known to be jointly convex in the number of docks and bikes at each station, which allows the computation of optimal allocations of bikes and docks. We generalize this result for arbitrary demand-realizations. We then define a Markov chain on the start-of-day number of bikes at each station, enabling us to determine the allocation of docks that minimizes the cost-function in steady-state. Since the stochastic dynamic program is the computational bottleneck, we

**Friday, 13:45-15:00**

**■ FD-01**

*Friday, 13:45-15:00 - Aula*

**Plenary Lecture and Closing Ceremony**

Stream: Plenaries

Chair: *Andreas Fink*

Chair: *Martin Josef Geiger*

**1 - Network Flow and Equilibrium Computation in the Linear Exchange Economy**

*Kurt Mehlhorn*

Leon Walras introduced an economic market model in 1874. In this model, every agent participating in the market has an initial endowment of some goods and a utility function over sets of goods. Goods are assumed to be divisible. The market clears at a set of prices if each agent can spend its entire budget (= the total value of its goods at the set of prices) on a bundle of goods with maximum utility, and all goods are completely sold. Market clearing prices are also called equilibrium prices. In the linear version of the problem, all utility functions are linear. For the case of linear utility functions, Walras' model is also known as the linear exchange economy. Walras argued the existence of equilibrium prices by describing an iterative improvement algorithm. However, his argument was incomplete. A convincing proof of existence was only given in the 1950 by Arrow and Debreu. The proof is non-constructive. Starting in the '70s, the quest for algorithms arose. The first algorithms were exponential. Later, polynomial time algorithms were derived based on the formulation of the problem as a convex program and the use of the Ellipsoid or the interior point method. In the technical part of the talk, we describe a combinatorial polynomial-time algorithm for computing equilibrium prices. We formulate the problem as a network flow problem in which the prices are modeled as capacities. We show that the problem can be solved by an iterative algorithm. In each iteration, we first adjust the prices and then compute a maximum flow. The adjustment of the prices is based on a careful examination of the current maximum flow. We also report on an implementation of the algorithm. (joint work with Ran Duan, Jugal Garg, and Omar Darwish).

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## Control Theory and Continuous Optimization

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**Track(s): 13**

## Decision Theory and Multiple Criteria Decision Making

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## Discrete and Integer Optimization

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## Energy and Environment

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## Game Theory and Experimental Economics

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## Graphs and Networks

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## Health Care Management

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## Logistics, Routing and Location Planning

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## Metaheuristics

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## Optimization under Uncertainty

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**Pricing and Revenue Management**

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**Security and Disaster Management**

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**Simulation and Stochastic Modeling**

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**Software and Modelling Systems**

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**Supply Chain Management**

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**Traffic and Passenger Transportation**

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# SESSION INDEX

## Wednesday, 9:00-10:30

WA-01: Opening Ceremony and Plenary Lecture (Aula) .....	1
--	---

## Wednesday, 11:00-12:30

WB-02: Exact Approaches for Mixed-Integer Nonlinear Optimization (i) (Hörsaal 1) .....	1
WB-03: Exact Algorithms for Hard Combinatorial Optimization Problems (Hörsaal 2) .....	2
WB-04: Model Based Energy System Planning (Hörsaal 3) .....	2
WB-05: Behavioral Operations Management (i) (Hörsaal 4) .....	3
WB-06: Business Track 1 (Hörsaal 5) .....	3
WB-07: Bilevel Network Games and Online Optimization (i) (Hörsaal 6) .....	4
WB-08: GOR Master Thesis Prize (Seminarraum 101/103) .....	4
WB-09: Finance I (Seminarraum 105) .....	5
WB-10: Flexibility in Revenue Management (Seminarraum 108) .....	5
WB-11: Managing Inventory Systems (Seminarraum 110) .....	6
WB-12: New Approaches (Seminarraum 202) .....	6
WB-13: Multiobjective Linear Optimization I (Seminarraum 204) .....	7
WB-14: Complexity in Multiobjective Combinatorial Optimization (Seminarraum 206) .....	7
WB-15: Project Scheduling Applications (i) (Seminarraum 305) .....	7
WB-16: Simulation in Health Care (Seminarraum 308) .....	8
WB-17: Demand Fulfillment in Hierarchies (Seminarraum 310) .....	9
WB-18: Location Routing (Seminarraum 401/402) .....	9
WB-19: Algorithm Engineering for Route Planning (i) (Seminarraum 403) .....	10
WB-20: Business and Industrial Analytics (Seminarraum 404) .....	10
WB-21: Stochastic and Exact Vehicle Routing (Seminarraum 405/406) .....	11

## Wednesday, 13:30-15:00

WC-02: Recent Advances in Mixed-Integer Linear and Non-linear Programming (i) (Hörsaal 1) .....	12
WC-03: Applied Mixed Integer Programming (i) (Hörsaal 2) .....	12
WC-04: Electric Mobility: Battery Technologies (Hörsaal 3) .....	13
WC-05: Behavioral Taxation (i) (Hörsaal 4) .....	13
WC-06: Business Track 2 (Hörsaal 5) .....	14
WC-07: Coordination Mechanisms in Logistics (i) (Hörsaal 6) .....	14
WC-08: Cross Docking and Stochastic Approaches (Seminarraum 101/103) .....	15
WC-09: Finance II (Seminarraum 105) .....	15
WC-10: Robust algorithms (Seminarraum 108) .....	16
WC-11: Lot Sizing (Seminarraum 110) .....	16
WC-12: Variable Neighbourhood Search (Seminarraum 202) .....	17
WC-13: Multiobjective Linear Optimization II (Seminarraum 204) .....	17
WC-14: Multiobjective Location and Routing Problems (Seminarraum 206) .....	18
WC-15: Scheduling Problems and Applications (i) (Seminarraum 305) .....	18
WC-16: Appointment Scheduling (Seminarraum 308) .....	19
WC-17: Supplier Selection and Closed-Loop Supply Chains (Seminarraum 310) .....	19
WC-18: Truck and Trailer Routing (Seminarraum 401/402) .....	19
WC-19: Delay Management and Re-Scheduling (i) (Seminarraum 403) .....	20
WC-20: Smart Services and Internet of Things (Seminarraum 404) .....	20
WC-21: Hours of Service Regulations (Seminarraum 405/406) .....	21

## Wednesday, 15:30-16:15

WD-02: Semi-Plenary Miettinen (Hörsaal 1) .....	22
WD-03: Semi-Plenary Woeginger (Hörsaal 2) .....	22

WD-04: Semi-Plenary Marklund (Hörsaal 3) .....	22
WD-06: Semi-Plenary GOR Unternehmenspreis (Hörsaal 5) .....	22

### Wednesday, 16:30-18:00

WE-02: Polyhedral Combinatorics (i) (Hörsaal 1) .....	23
WE-03: Combinatorial Optimization II (Hörsaal 2) .....	23
WE-04: Energy Management in the Steel Industry (Hörsaal 3) .....	23
WE-05: Coordination Games (Hörsaal 4) .....	24
WE-06: GOR Dissertation Prize (Hörsaal 5) .....	24
WE-07: Game Theory and Incentives (Hörsaal 6) .....	25
WE-08: Network Design for Distribution Logistics (Seminarraum 101/103) .....	26
WE-09: Finance III (Seminarraum 105) .....	26
WE-11: Sequencing and Scheduling (Seminarraum 110) .....	27
WE-12: Approximate Dynamic Programming: Methods and Applications (Seminarraum 202) .....	27
WE-13: Optimal Control for Supply Chain and Operations Management I (Seminarraum 204) .....	28
WE-14: MCDM Applications and Case Studies (Seminarraum 206) .....	28
WE-15: Complex scheduling problems (i) (Seminarraum 305) .....	29
WE-16: Data Analytics (Seminarraum 308) .....	29
WE-18: Collaborative Transportation Planning II (i) (Seminarraum 401/402) .....	30
WE-19: Resource Scheduling in Public Transportation (i) (Seminarraum 403) .....	30
WE-20: Forecasting (Seminarraum 404) .....	31
WE-21: Storage Systems Optimization (Seminarraum 405/406) .....	32

### Thursday, 9:00-10:30

TA-02: Mixed Integer and Linear Programming Software (i) (Hörsaal 1) .....	33
TA-03: Selected Topics of Discrete Optimization (Hörsaal 2) .....	33
TA-04: Applications in energy modelling (Hörsaal 3) .....	33
TA-05: Behavioral Project Management (i) (Hörsaal 4) .....	34
TA-06: Advanced Analytics in Revenue Management (Hörsaal 5) .....	34
TA-07: Behavioral Contracting (i) (Hörsaal 6) .....	35
TA-08: Container and Terminal Operations I (i) (Seminarraum 101/103) .....	35
TA-09: Modeling and Solver Performance (Seminarraum 105) .....	36
TA-10: Advances in Stochastic Optimization (Seminarraum 108) .....	36
TA-11: Production Scheduling (Seminarraum 110) .....	37
TA-12: Graphs and Networks (Seminarraum 202) .....	37
TA-13: Error Bounds and Algorithms (Seminarraum 204) .....	38
TA-14: Scalarizations, Bounds and Mathematical Programming Methods (Seminarraum 206) .....	38
TA-15: Flows and Queues (Seminarraum 305) .....	38
TA-16: Planning health care services (Seminarraum 308) .....	39
TA-18: Collaboration In Logistics (Seminarraum 401/402) .....	40
TA-19: Integrated Public Transportation Planning (i) (Seminarraum 403) .....	40
TA-20: Forecasting with Artificial Neural Networks (Seminarraum 404) .....	41
TA-21: Airspace Networks (Seminarraum 405/406) .....	41

### Thursday, 11:00-12:30

TB-02: Combinatorial Optimization (i) (Hörsaal 1) .....	42
TB-03: Flexibility options in power markets (Hörsaal 2) .....	43
TB-04: Demand Response and decentralized systems (Hörsaal 3) .....	43
TB-05: Mechanism and Markets for IT Service Compositions (Hörsaal 4) .....	44
TB-06: Robust Revenue Management (Hörsaal 5) .....	44
TB-07: New Results for Shipping, Matching, and Covering (Hörsaal 6) .....	44
TB-08: Collaborative Transportation Planning I (i) (Seminarraum 101/103) .....	45
TB-09: Algebraic Modeling Languages (Seminarraum 105) .....	45
TB-10: Multistage uncertain problems (Seminarraum 108) .....	46
TB-11: Multi-stage Production Systems (Seminarraum 110) .....	46
TB-12: Scheduling and Sequencing: Applications (Seminarraum 202) .....	47



TB-13: Simulation Models I (Seminarraum 204) . . . . .	47
TB-14: Decision Making with Incomplete or Imprecise Information (Seminarraum 206) . . . . .	48
TB-15: Resource Constrained Project Scheduling (Seminarraum 305) . . . . .	48
TB-16: Resource scheduling (Seminarraum 308) . . . . .	49
TB-17: Coordination and Collaboration (Seminarraum 310) . . . . .	49
TB-18: Container and Terminal Operations II (i) (Seminarraum 401/402) . . . . .	50
TB-19: Learning Robust Routes (i) (Seminarraum 403) . . . . .	50
TB-20: Analytics in Mobility (Seminarraum 404) . . . . .	51
TB-21: Facility and Hub Location Problems (Seminarraum 405/406) . . . . .	51

### Thursday, 13:30-14:15

TC-02: Semi-Plenary Walther (Hörsaal 1) . . . . .	52
TC-03: Semi-Plenary Correa (Hörsaal 2) . . . . .	52
TC-04: Semi-Plenary Hurink (Hörsaal 3) . . . . .	52
TC-06: Semi-Plenary Spieksma (Hörsaal 5) . . . . .	53

### Thursday, 14:45-16:15

TD-02: Advances in Mixed Integer Programming (i) (Hörsaal 1) . . . . .	53
TD-03: Sustainable Resource Management (Hörsaal 2) . . . . .	53
TD-04: Investment planning and portfolios in energy markets (Hörsaal 3) . . . . .	54
TD-05: Sequential Scheduling Games (i) (Hörsaal 4) . . . . .	54
TD-06: Revenue Management for Urban Transportation (Hörsaal 5) . . . . .	54
TD-07: Gas Network Optimization (i) (Hörsaal 6) . . . . .	55
TD-08: Emission Oriented Transportation Planning (i) (Seminarraum 101/103) . . . . .	55
TD-09: Solver Approaches (Seminarraum 105) . . . . .	56
TD-10: Sourcing and Capacity Management in Uncertain Environments (Seminarraum 108) . . . . .	56
TD-11: Advances Production and Operations Management (Seminarraum 110) . . . . .	57
TD-12: Real-World Applications (Seminarraum 202) . . . . .	57
TD-13: Simulation Models II (Seminarraum 204) . . . . .	58
TD-14: Rankings, Goals and (Integer) Linear Programming (Seminarraum 206) . . . . .	58
TD-15: Robust Scheduling (Seminarraum 305) . . . . .	59
TD-16: Decision Support and Scheduling (Seminarraum 308) . . . . .	60
TD-17: Supply Chain Reliability and Risk (Seminarraum 310) . . . . .	60
TD-18: Liner Shipping Optimization II (i) (Seminarraum 401/402) . . . . .	60
TD-19: Passenger Routing in Public Transportation Problems (i) (Seminarraum 403) . . . . .	61
TD-20: Sequential and Temporal Data Analysis (Seminarraum 404) . . . . .	62
TD-21: Bi-Objective Vehicle/Ship Routing (Seminarraum 405/406) . . . . .	62

### Friday, 9:00-10:30

FA-02: Paths, Trees, and Tours (Hörsaal 1) . . . . .	64
FA-03: Resource and Energy Efficiency (Hörsaal 2) . . . . .	64
FA-04: Optimisation and decomposition in energy markets (Hörsaal 3) . . . . .	65
FA-05: Congestion Games (i) (Hörsaal 4) . . . . .	65
FA-06: Pricing and Service Design (Hörsaal 5) . . . . .	66
FA-07: Technical Applications of OR Methods (i) (Hörsaal 6) . . . . .	66
FA-08: Liner Shipping Optimization I (i) (Seminarraum 101/103) . . . . .	67
FA-09: Evacuation Planning (Seminarraum 105) . . . . .	67
FA-10: Robust optimization and applications (Seminarraum 108) . . . . .	68
FA-12: Combinatorial Optimization: Applications (Seminarraum 202) . . . . .	68
FA-13: Control Theory and Continuous Optimization (Seminarraum 204) . . . . .	69
FA-14: Simulation in Safety & Security & Social Science (Seminarraum 206) . . . . .	70
FA-15: Crew Scheduling (Seminarraum 305) . . . . .	70
FA-16: Project Scheduling (Seminarraum 308) . . . . .	71
FA-17: Sustainable supply chains (Seminarraum 310) . . . . .	71
FA-18: Complex Vehicle Routing Problems (Seminarraum 401/402) . . . . .	71
FA-19: Applications of Timetable Optimization in Public Transport (i) (Seminarraum 403) . . . . .	72

FA-20: Railway Applications (i) (Seminarraum 404) .....	72
FA-21: Heuristic Vehicle Routing (Seminarraum 405/406) .....	73

### Friday, 11:00-11:45

FB-02: Semi-Plenary Klein (Hörsaal 1) .....	74
FB-03: Semi-Plenary Schultz (Hörsaal 2) .....	74
FB-06: Semi-Plenary Sørensen (Hörsaal 5) .....	74

### Friday, 11:45-13:15

FC-02: Two-dimensional Packing Problems (Hörsaal 1) .....	75
FC-03: Environmental Aspects of Electric Mobility (Hörsaal 2) .....	76
FC-04: Energy Storages (Hörsaal 3) .....	76
FC-05: Equilibrium Computation (i) (Hörsaal 4) .....	77
FC-06: Innovative Applications in Pricing and Revenue Management (Hörsaal 5) .....	77
FC-07: Networks and Flows (Hörsaal 6) .....	78
FC-08: Districting Problems in Business and Public Organizations (i) (Seminarraum 101/103) .....	78
FC-09: Preparedness in Civil Security and Humanitarian Aid (Seminarraum 105) .....	79
FC-10: Applications of uncertain optimization (Seminarraum 108) .....	79
FC-11: Stochastic Models in Operations (Seminarraum 110) .....	80
FC-12: Combinatorial Optimization: New Approaches (Seminarraum 202) .....	80
FC-13: Optimal control for supply chain and operations management II (Seminarraum 204) .....	81
FC-14: Queueing Networks (Seminarraum 206) .....	81
FC-15: Scheduling with MIPs (Seminarraum 305) .....	82
FC-16: Multi Machine Scheduling (Seminarraum 308) .....	82
FC-17: Supply chain planning and lot-sizing (Seminarraum 310) .....	83
FC-18: Efficient Neighborhood Search for Vehicle Routing Problems (Seminarraum 401/402) .....	83
FC-19: Polyhedral and Heuristic Methods for Railway Timetabling (Seminarraum 403) .....	84
FC-20: Advances in Railway Transportation (i) (Seminarraum 404) .....	84
FC-21: Facility Location and Capacity Problems (Seminarraum 405/406) .....	85

### Friday, 13:45-15:00

FD-01: Plenary Lecture and Closing Ceremony (Aula) .....	86
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# SCHEDULE OVERVIEW

## Wednesday, August 31

Start	End		
09:00	10:30	WA	Opening & Keynote Van Wassenhove (Aula)
11:00	12:30	WB	Sessions
13:30	15:00	WC	Sessions
15:30	16:15	WD	Semi-Plenary Speakers Miettinen (HS1) Woeginger (HS2) Marklund (HS3) Unt.-Preis (HS5)
16:30	18:00	WE	Sessions
19:30	22:30		Reception (IMM)

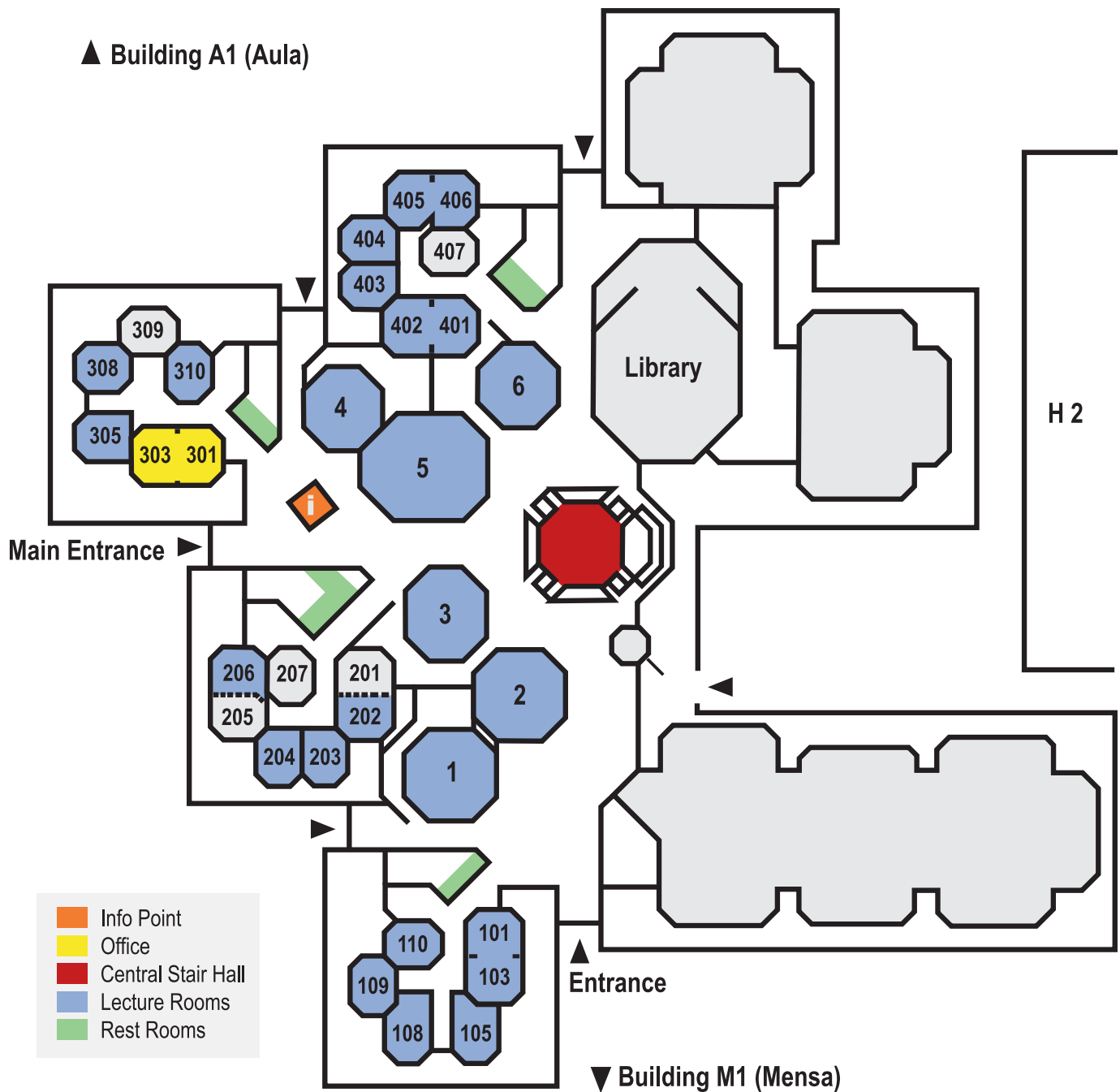
## Thursday, September 1

Start	End		
09:00	10:30	TA	Sessions
11:00	12:30	TB	Sessions
13:30	14:15	TC	Semi-Plenary Speakers Walther (HS1) Correa (HS2) Hurink (HS3) Spijksma (HS5)
14:45	16:15	TD	Sessions
16:30			GOR General Meeting (HS5)
19:30			Conference Dinner (Altantic)

## Friday, September 2

Start	End		
09:00	10:30	FA	Sessions
11:00	11:45	FB	Semi-Plenary Speakers Klein (HS1) Schultz (HS2) Sörensen (HS5)
11:45	13:15	FC	Sessions
13:45	15:00	FD	Keynote Mehlhorn & Closing (Aula)

# FLOOR PLAN BUILDING H1



## ANNUAL INTERNATIONAL CONFERENCE 2016 OF THE GERMAN OPERATIONS RESEARCH SOCIETY

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