Photos page 3 and 4: Thor Balkhed, LiU
Welcome to RailNorrköping 2019, the 8th International Conference on Railway Operations Modelling and Analysis, held at Linköping University, campus Norrköping, in Sweden, on June 17th – 20th, 2019.

Organization Committee

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Jinchuan Zhang, Beijing Jiaotong University
Jun Zhao, Southwest Jiaotong University
Dear railway researchers, colleagues and friends,

the organization committee is happy to welcome you to Norrköping and the 8th International Conference on Railway Operations Modelling and Analysis, RailNorrköping 2019.

In times when global warming and climate changes are topping the news world-wide, it is very satisfying to see the growing interest for energy-efficient and sustainable railway travel and transports. On a high level this conference is an important contribution to how the railway system can develop and accommodate an increasing portion of traffic. No matter if we improve the distribution of run-time margins, formulate mathematical programs for timetable construction, or discuss dispatching strategies in disturbed situations, all contributions are needed. The conference program has both depth and width, and we hope that all participants both can find other researchers addressing the same problem and get inspiration for coming research projects. A new initiative this time is to invite professional presentations from the industry, and we hope that this helps us to link the research community closer to the stakeholders, and future user of the research results. The organization committee for RailNorrköping 2019 has also invited the sponsors to set up show-cases in the foyer and we hope this also gives rise to fruitful discussions with the branch organizations.

We know that some of you are visiting Scandinavia for the first time, and we hope you will enjoy not only the RailNorrköping 2019 venue, but also take your time to explore a beautiful country at the best time of the year, whether that could be by taking part in one of the many Midsummer celebrations on Friday June 21st, travelling Scandinavia’s longest narrow-gauge railway Hultsfred–Västervik in the typical rail cars from the 1950s, or taking night train 94 to the never setting midnight sun in subarctic Lapland. Travelling with your family, we can recommend the amusement park Astrid Lindgren’s värld, where you and your children can meet Pippi Longstocking and all other well-known characters from Astrid Lindgren’s books, and the zoo park Kolmården’s djurpark, known for its dolphins, both of which can be reached in a day-trip from Norrköping.

Clearly, an event like RailNorrköping 2019 would not have been possible without a lot of help and support of various kind. We are grateful to all sponsoring organizations, the hosting Linköping university and other Swedish universities and research institutes contributing in various ways. We are also thankful to all researchers world-wide who have reviewed manuscripts and hereby helped us to set the high scientific standards for the conference. And last, but not least, there are so many of you---none mentioned, none forgotten---helping in the most intricate ways by spell-checking, setting up signs, printing programs, ordering food and refreshments and so on: We did this all together!

On behalf of the organization committee

Anders Peterson, Conference Chair
KEYNOTE SPEAKERS

Gunnar Alexandersson
Senior researcher, Stockholm School of Economics
Senior adviser, regulations and international affairs, SJ AB

Monday, June 17th, 10:10-10:40

Railway Market Opening and Organisational Reforms in Sweden

Abstract:

The Swedish railway sector has been in the forefront in Europe when it comes to regulatory reforms, organisational changes and market opening since the late 1980s. This plenary presentation gives an overview of the changes, the various steps in the reform process, and the current organisation. The experience and effects of the reforms (both positive and negative) are presented in terms of a number of developments: infrastructure investments, national and regional demand for rail services, market entry, tenders, prices, punctuality, safety, speed and capacity etc. An overall assessment summarizes the pros and cons and some current issues that remain to be handled.

About Gunnar Alexandersson:

Gunnar Alexandersson is a senior researcher in transport economics at Stockholm School of Economics, with numerous publications in journals, books and reports. His PhD thesis tracked the origin, development and effects of regulatory reforms in the Swedish bus and railway sectors from 1979 and onwards. In 2007-2008 he worked as senior economics policy adviser at the Community of European Railways and Infrastructure Companies in Brussels, dealing with dossiers on e.g. infrastructure charging and the internalisation of external costs of transport. In 2012-2013 he was deputy CEO at the Association of Swedish Train Operating Companies, addressing issues related to regulations and market opening. In May 2013 Gunnar Alexandersson was appointed by the Swedish Government to lead a committee looking into the current and future organisation of the railway sector, resulting in two intermediate reports and one final report. This work was concluded in December 2015. Since September 2016 he holds a part-time position as senior adviser on regulations and international affairs at the Swedish railway operator SJ AB. Following from his role as senior researcher at Stockholm School of Economics, he is a member of the International Steering Committee to the bi-annual International Conference on Competition and Ownership in Land Passenger Transport (Thredbo), which he co-organised in Stockholm in 2017. He is also chairing the railway passenger subgroup to the European Commission’s Railway Undertakings Dialogue since November 2018.
Rob Goverde  
Professor of Railway Traffic Management & Operations,  
Department of Transport & Planning, TU Delft, The Netherlands

Tuesday, June 18th, 13:10-13:30

Railway operations research and the development of digital railway traffic systems

Abstract:

Railways are essential for the sustainable accessibility of the big cities and the national and international mobility. Many urban and national railway networks face increasing capacity saturation issues, while the transport demand keeps growing for both passengers and freight. Likewise, high-speed networks in Europe and China are expanding rapidly and attract more and more passengers as sustainable and fast alternative for flying. And similar to the demand for international freight train corridors that often share tracks with national passenger railway networks. To enable this growth the railways are in a transition to modern digital railway traffic systems with continuous wireless communication for efficient signalling and traffic management. The timetable becomes increasingly more accurate to allow optimized infrastructure occupation, while train operation is supported by driver advisory systems connected to intelligent traffic management systems. Automatic train operation is already the standard in modern metro systems and will also be applied to other railway systems to realize the highest capacity consumption. The transfer to this modern digital technology is a challenge to the railway sector and requires an innovative integrated approach with the aim to achieve a safe, efficient and reliable transport system. This presentation gives an overview of the challenges ahead and the role of railway operation research in these innovations.

About Rob Goverde:

Rob Goverde is Professor of Railway Traffic Management & Operations and Director of the Digital Rail Traffic Lab at Delft University of Technology. He has an MSc in Mathematics from Utrecht University, a Professional Doctorate in Engineering (PDEng) in Mathematical Modelling and Decision Support from Delft University of Technology, and a PhD in Railway Operations from Delft University of Technology. He has more than 25 years of experience in railway traffic planning and management. He is the author of more than 135 peer reviewed papers, and supervised 12 PhD students and 50 MSc students. He is also Editor in Chief of the Journal of Rail Transport Planning & Management, Associate Editor of the IEEE Transactions on ITS, Fellow of the Institution of Railway Signal Engineers (IRSE), and board Member of the International Association of Railway Operations Research (IAROR).
What is the social value of railway capacity?
Connecting transport economics and railway operations research

Abstract:
The link between transport economics and railway operations analysis is unfortunately rather weak, even if there are notable exceptions of people and studies bridging the gap. The aim of this keynote is therefore to illustrate how concepts and methods from transport economics can be useful for railway operations analysis, in particular analyses of capacity and regulations. I argue that the two fields have much to gain from a closer integration. I will do this by discussing three issues: a) timetable assumptions in cost-benefit analysis (CBA) of increased capacity, b) crowding costs in public transport CBA, and c) slot trading between operators in open-access railway markets.

About Jonas Eliasson:
Jonas Eliasson is visiting professor of transport systems at Linköping university. He was Director of the Stockholm City Transportation Administration 2016-2018 and professor of transport systems analysis at the Royal Institute of Technology (KTH) 2007-2016.

His research interests focus on transport policy design and evaluation, including areas such as cost-benefit analysis, transport pricing, railway capacity allocation, transport demand modeling, congestion charges, decision making in the transport sector, public and political acceptability of transport policies, and valuations of travel time and reliability.

Prof. Eliasson has a long involvement in analyzing, developing and applying transport policies and appraisal methodologies. He has been engaged as expert advisor to a large number of urban, regional and national governments around the world regarding strategic transportation issues, often involving sustainable transport planning, transport pricing and social and economic appraisal. He directed the design and evaluation of the Stockholm congestion pricing system, in operation since 2006, and has subsequently been heavily involved with its evaluation and redesign, as well as the design and evaluation of the Gothenburg congestion pricing system, in operation since 2013. He has chaired the national committee for analysis of the National Transport Investment Plan, and has been a member of the standing expert advisory board to the National appraisal guidelines committee. He is an elected member of the Royal Academy of Engineering Sciences, and member of several scientific committees and editorial boards.
**LOCATION**

RailNorrköping 2019 will be held at Linköping University/Campus Norrköping. All activities (except for welcoming reception, conference dinner and technical visit, see below) will take place in building Kåkenhus, floor level 2, which you enter easiest from Kungsgatan 40.

**PARALLEL SESSIONS**
Parallel sessions of the conference will be held in rooms K1, K2, K3, K4 in the Kåkenhus building. Session A is in K4, session B in K2, session C in K1, and session D in K3.

**KEYNOTES**
Keynote talks will be held in room K4.

**REGISTRATION DESK AND CLOAK ROOM** will be located in K22, and will close 30 minutes after the last session. It will also be open Sunday, June 16, 17:00-18:30.

**CONFERENCE DINNER** will take place in Värmekyrkan.

**SHORT COURSES** will take place in K2.

**WELCOME RECEPTION** on Sunday, June 16, 18:30-21:00, will be located at Visualization Center. A program including a demonstration of the visualization center will start at 19:00—please be on time! (Better: have 15 spare minutes for division into groups.) For your convenience, the registration desk in Kåkenhus will also be open 17:00-18:30 on Sunday, June 16.
THINGS TO SEE IN NORRKÖPING

For more detailed information on what to do in Norrköping see https://upplev.norrkoping.se/en

VISUALIZATION CENTER C
Visualization Center C is a research and science center in Norrköping, Sweden, conducting a unique mix of leading visualization research and public outreach activities. The center hosts a large-scale arena for public visits and events including media labs, interactive exhibitions and an immersive 3D full dome theatre. Step into our world and discover the experiences we offer; experiences in every sense of the word, from award-winning full dome productions and interactive exhibits to consulting services and research partnerships.

THE MUSEUM OF WORK
The museum depicts working life and working conditions through exhibitions, seminars and programme activities. The museum of work should be an innovative meeting place which promotes discussion on peoples work, lives and conditions.

KNÄPPINGSBORQ QUARTER
A unique environment in Norrkoping City. A historic neighborhood where the oldest buildings are from 1767. Now you can shop, snack, eat and enjoy life in Knäppingsborg.

THE INDUSTRIAL LANDSCAPE
Few European cities can boast such a well-preserved industrial area as Norrköping. In Sweden’s "Manchester" the industrial development started in the 17th century and carried on through to the middle of the 20th century. Along the banks of the Motala Ström—Motala River—a number of woollen spinning mills and cotton factories were established. By the middle of the 19th century, Norrköping was the second largest industrial city in Sweden. 70% of Sweden’s textiles were woven here. Both the conference and dinner venue are part of the industrial landscape.
USEFUL INFORMATION

CONTACT AND VENUE ADDRESS
RailNorrköping 2019
Linköping University, Campus Norrköping
Kungsgatan 40
602 21 Norrköping
Sweden
https://www.railnorrkoping2019.org/
info@railnorrkoping2019.org

INTERNET ACCESS
Conference delegates can use eduroam or the username and password given out at registration. The code works on several devices.

EMERGENCY NUMBERS
In case of emergency 112
Conference organization +46700- 896544
HaCon
With nearly 30 years of experience, HaCon has established itself as a leading European player for planning, scheduling and information solutions. HaCon’s TPS solutions for train planning and capacity management enable network providers and operators to make the most of their infrastructure and significantly improve their work and business processes regarding operative timetable planning and real-time dispatching. TPS Online, the new member of the TPS family, has been developed specifically for ad-hoc train dispatching that controls and optimizes everyday rail operations. Short-term disruptions such as delays, broken shunting points or signaling systems can be processed in real time. TPS Online detects conflicts that have an impact on the entire railway network and offers automatic, semi-automatic, and manual conflict resolutions. As a result, dispatchers can now immediately respond to disturbances, for example by advising trains to wait for each other, by redirecting them or by scheduling a change of track.

The high quality software products and solutions prompted the Massachusetts Institute of Technology (MIT) to honour HaCon as one of the “50 Smartest Companies” worldwide. Since 2017, HaCon has been a member of the Siemens family. Headquartered in Hannover, Germany, HaCon also holds offices in Berlin, Paris, New York and London.

OpenTrack Railway Technology Ltd.
OpenTrack Railway Technology Ltd. develops and markets simulation tools for public transport systems, and develops data exchange formats for railway applications. OpenTrack Railway Technology is a spinoff-company from the ETH Zurich.

The company was founded in 2006. Locations are in Zurich (Switzerland) and Vienna (Austria). In further countries local distributors are responsible for the distribution and marketing of our simulation tool OpenTrack (Italy, Czech Republic, Australia, Brazil, Malaysia, China).

OpenTrack is a railway simulation tool developed at the ETH Zurich. It is a catalyst for practical economic solutions to complex railway technology problems. OpenTrack Railway Technology also provides consulting services in railway information technology.
**Ramboll**

Ramboll is a leading engineering, design and consultancy company founded in Denmark in 1945.

The company employs more than 14,000 experts globally and has especially strong representation in the Nordics, UK, North America, Continental Europe, Middle East and Asia-Pacific.

With 300 offices in 35 countries, Ramboll combines local experience with a global knowledgebase constantly striving to achieve inspiring and exacting solutions that make a genuine difference to our clients, the end-users, and society at large.


We partner with our clients to create sustainable societies where people and nature flourish.

With our unique combination of technical excellence and socio-economic insights we deliver enduring structures, resource-efficient solutions and socially cohesive communities for today and tomorrow. We have a multidisciplinary approach to what we do and what we aspire to achieve. We work to create a sustainable society where improved quality of life and economic growth is enabled by innovative and durable solutions to the most pressing needs, challenges and concerns for businesses, public institutions and people. Often these challenges are related to the physical environment in which life unfolds – natural resources, infrastructure, buildings and structures, urban spaces – and our ambition is to help drive a sustainable transition towards a more resource efficient future.

**TrenoLab**

With the same passion and care of a carpenter giving shape to wood, TrenoLab blends big data analysis, sophisticated simulation, remarkable experience and passion to develop effective solutions for improving railway operations.

Our highly skilled team of transport, railway and computer experts combine professional experience with the latest findings from academic research. In only a few years we have
become a worldwide leader in operations planning for all types of rail-based transport from metros to high-speed lines, for projects ranging from day-to-day operations to long-term planning.

**treno**lab has developed a suite of software tools designed to help quickly and effectively solve complex railway operations problems: **trenissimo** is an entirely new simulation tool designed to make the simulation more intuitive, accurate, and effective in its support to the various stages of planning. **treno**analysis explores railway traffic data, representing them using a wide range of diagrams and statistics at different aggregation levels, while **treno**plus is a smart working space and a unique combination of micro and macroscopic models to reach the highest planning accuracy in a few clicks.

**Sweco**
Sweco plans and designs the communities and cities of the future. The results of our work are sustainable buildings, efficient infrastructure and access to clean water. With 15,000 employees in Northern Europe, we offer our customers the right expertise for every project. We carry out projects in 70 countries annually throughout the world. Sweco is Europe’s leading architecture and engineering consultancy, with sales of approximately SEK 16.9 billion (EUR 1.8 billion). The company is listed on NASDAQ OMX Stockholm AB.

**VTI**
VTI, the Swedish National Road and Transport Research Institute, delivers innovative applied research on commission. The research is carried out within the areas of traffic, transport and infrastructure and covers all transport modes. One core area of expertise is railways and rail bound transport.

VTI is a governmental agency with 220 employees in an interdisciplinary organization. The institute has the right to appoint professors and currently has professors in pavement technology, human-machine interaction, environment and transport economics.

The academic and scientific competence together with advanced testing equipment make VTI a prominent actor, both nationally and internationally.

**Norrköpings kommun**
The municipality of Norrköping.
SUPPORTING ORGANIZATIONS

LiU (Linköping University)
In close collaboration with the business world and society, Linköping University (LiU) conducts world-leading, boundary-crossing research in fields including materials science, IT and hearing. In the same spirit, the university offers many innovative educational programmes, many of them with a clear vocational focus, leading to qualification as, for example, doctors, teachers, economists and engineers.

The university has 32,000 students and 4,000 employees on four campuses. Together we seek answers to the complex questions facing us today. Our students are among the most desirable in the labour market and international rankings consistently place LiU as a leading global university.

LiU achieved university status in 1975 and innovation is our only tradition.

KTH (Royal Institute of Technology Stockholm)
Since its founding in 1827, KTH Royal Institute of Technology in Stockholm has grown to become one of Europe’s leading technical and engineering universities, as well as a key centre of intellectual talent and innovation. We are Sweden’s largest technical research and learning institution and home to students, researchers and faculty from around the world dedicated to advancing knowledge.

RISE (Research Institutes of Sweden)
RISE is a unique mobilisation of resources to increase the pace of innovation in our society. By gathering a number of research institutes and over a hundred test beds and demonstration environments under the umbrella of a single innovation partner, we create improved conditions for society’s problem solvers.

We gather around challenges and organise ourselves accordingly. Together, specialists in disparate fields innovate and resolve tough problems. Depending on the nature of the challenge and our assignment, we take on a variety of roles in the innovation system, and develop new ones as and when required.

We are owned by the Swedish State and work in collaboration with and on behalf of the private and public sectors and academia. Together, we develop services, products, technologies,
processes and materials that contribute to a sustainable future and a competitive Swedish business community.

KAJT (Capacity in the Railway Traffic System).
The Swedish Transport Administration (Trafikverket), along with seven academic partners, Linköping University, Blekinge Institute of Technology, Royal Institute of Technology (KTH), SICS Swedish ICT, The Swedish National Road and Transport Research Institute (VTI), Uppsala University, and Lund University, are jointly running a research program known as “Capacity in the railway traffic system” (in Swedish: Kapacitet i järnvägstrafiken – KAJT). The program was established in January 2013. The core activity is in the development of processes and innovations in the field of capacity planning and traffic management from operational service to 40 years in the future.

Trafikverket
Trafikverket is the Swedish Transport Administration, responsible for the overall long-term infrastructure planning of road, rail, sea and air transport. Our assignment also includes the construction, operation and maintenance of state roads and railways. We are developers of society and we plan ahead for a holistic integration of the entire transport system.

Our vision is that everyone arrives smoothly, the green and safe way. This means that we will create the conditions for a robust and efficient transport system which is both energy-efficient and safe. At the same time, we must ensure that road-users and hauliers have excellent opportunities to carry out their journeys and transportation. The objective is an accessible and safe transportation system that takes account of the environment and people's health. To achieve this objective, we need to work closely with the rest of society. Together, we can make life easier for the whole of Sweden.
TECHNICAL VISIT TO HALLSBERG

On Wednesday afternoon, June 19th, there is a technical excursion to Hallsberg, where we in smaller groups will visit the shunting yard (shunting tower), the freight operator Green Cargo’s headquarter and TXG’s workshop with wheel revolution as specialty. The number of participants is limited, and if you have signed up for this event but will not be able to join, please inform the staff in the cloakroom or earlier via info@railnorrkoping2019.org so we can invite new persons from the reserve list.

Some practical information about the visit:

1. We will travel to Hallsberg by a chartered train, departing Norrköping Central station shortly after the last session. The platform and precise departure time will be announced at the conference.

2. Walking time from the conference venue is approximately 20 minutes, and we kindly ask all participants to be punctual. Lunch boxes will be handed out at the venue, but we recommend eating them during the train ride (ca 50 minutes).

3. The visit in Hallsberg includes some walking on uneven areas and embarking/disembarking trains without proper platforms. We advise you to wear comfortable shoes. Participants with reduced mobility are kindly asked to inform the staff before departure so that we can assist in the best way.

4. The precise return time from Hallsberg will be announced later, but we expect to arrive in Norrköping no later than 19.00. You are free to leave the group in Hallsberg and arrange the onward journey on your own, but please inform the staff.
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<td>55 A novel timetabling procedure which considers running speed of trains and its application to actual cases</td>
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<td>Implementation of new timetable rules for increased robustness - case study from the Swedish Southern mainline</td>
<td>Emma Solinen</td>
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<td>Impact of perturbations calibration in simulation: the case of robustness evaluation at station</td>
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<td>Robust Capacitated Train Rescheduling with Passenger Reassignment under Stochastic Disruption Durations</td>
<td>Xin Hong</td>
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<td>Mining Train Delay Propagation Pattern from Train Operation Records in a High-Speed System</td>
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ABSTRACTS

MONDAY, JUNE 17

SESSION 4A: 11:10-12:30 TRAFFIC MANAGEMENT 1

Real-Time Train Rescheduling in High-frequency Metro Systems during Partial Blockages
Fengbo Liu, Yongqiu Zhu, Nikola Besinovic, Rob Goverde and Ruihua Xu

With high frequency and unavoidable disruptions, metro systems are nowadays undertaking great emphasis on disruption management. This paper proposes a mixed integer programming model for train rescheduling in high-frequency metro systems during partial blockages. Several train rescheduling strategies are formulated into the model that considers station capacity and rolling stock circulation. The model is applied to a busy line of the Shanghai metro network. The computation time meets the real-time application requirement. The case study presents different influences of various disruption scenarios and emergency train constraints on the optimal solution.

A Survey on Decomposition Principles and Methods for the Problem of Railway Traffic Management
Florin Leutwiler and Francesco Corman

Providing punctual, reliable and enough services to customers is one main goal of railway network operators. By automation of train scheduling, it is possible to schedule and route trains on the network closer to its maximal capacity, which is of great value for network operators. In this survey we state the general formulation of the railway scheduling problem and show the principle of decomposition as a way to tackle it. The literature shows many different decomposition approaches. With a survey we aim to summarize existing research and state possible new directions for future research.

Distributed optimization approaches for the integrated problem of real-time railway traffic management and train control
Xiaojie Luan, Bart De Schutter, Ton van den Boom, Lingyun Meng, Gabriel Lodewijks and Francesco Corman

This paper aims at improving the computational efficiency of an integrated optimization problem (PC) for large-scale cases. Two decomposition methods are considered, namely a geography-based decomposition and a train-based decomposition. We propose an integer linear optimization approach to implement the geography-based decomposition of the integrated optimization problem. With the decomposition, a number of sub-problems (that correspond to partitions of a railway network or trains) with couplings are obtained. We further introduce three distributed optimization approaches to deal with the couplings among the sub-problems. Experiments are conducted to examine the performance of the three proposed distributed optimization approaches, in terms of feasibility, computational efficiency, solution quality, and (estimated) optimality.

An Optimization Model for Rescheduling Trains to Serve Unpredicted Large Passenger Flow
Junduo Zhao, Haiying Li, Lingyun Meng and Francesco Corman

Rail transportation plays an important role in the rapidly changing multimodal transportation market for its stability and reliability, which is vital for train operating companies to maintain its competitiveness. Serving different kinds of passengers in emergency situation is a reflection of reliability of rail transportation. While unavoidable stochastic perturbations (e.g. bad weather) disrupt air transportation causing interruptions, rail rescheduling demand is produced deriving from the interruption of air transport, which defined as Unpredicted Large Passenger Flow (simply for ULPF) in this paper. The problem encountered by dispatchers is to reschedule trains to serve ULPF. We address the optimization problem of rescheduling trains to serve ULPF causing by interruptions of air transportation. In this paper, we focus on the rescheduling of High-speed Railway to evacuate ULPF, since the characteristic of air transport passengers, which are willing to pay high cost for short time, is different from other modes. Three dispatching strategies, which are organizing the seats remained, inserting new trains and the combination of the above two with transfer (e.g. passengers arrive at the destination through transfer between existing train and inserting new train), are used to reschedule ULPF in this paper. Moreover, an Integer Linear Programming (ILP) model is constructed for rescheduling trains to serve ULPF. The proposed model is solved by a standard ILP solver.

SESSION 4B: 11:10-12:30 CAPACITY ANALYSIS 1
Infrastructure capacity in the ERTMS signalling system
Alex Landex and Lars Wittrup Jensen

This article describes the main differences between level 1-3 in the new European signaling standard ERTMS and conventional signaling systems focusing on communication differences, the ability to look ahead and braking curves. Based on this description, the capacity differences between level 1 and 2 are investigated for theoretical as well as real-life cases using line headway calculation models developed for the study. The results show ERTMS level 2 generally has shorter headways than level 1 and hence higher capacity. However, in homogeneous operation where the braking distance is well-adapted to the block lengths, level 1 can have shorter headways than level 2 due to less system delays. The results also show that Level 2 due to continuous update of the Movement Authority (MA), result in higher capacity than level 1 for longer block sections and lower speeds. The article discusses that a 1:1 replacement of conventional signaling with ERTMS can lead to loss of capacity as the ERTMS braking curves are likely to be longer. The article also discusses how extra capacity can be gained with ERTMS as it is possible to look more block sections ahead.

A Study of the Performance and Utilization of High Speed Rail in China based on UIC 406 Compression Method
Jie Li, Dian Wang, Qiyuan Peng and Yuxiang Yang

Many HSR lines in China are heavily utilized, and it is desired to declare the bottlenecks in the railway network.
UIC Code 406 is an easy and effective way of calculating the capacity consumption (UIC (2004)). Based on the UIC 406 capacity method, the capacity consumption of railway infrastructure can be measured by compressing the timetable graphs.

The paper analyses the characteristics of Chinese railway operation and the features of the compress timetable method proposed by UIC 406. Regarding the UIC 406 capacity leaflet as a framework, the paper builds a calculation and assessment framework for Chinese HSR capacity, presents a capacity calculation model based on the compress timetable method and determine the capacity bottleneck in the rail. In this paper, the UIC 406 based capacity calculation model is applied to evaluate the capacity consumption of Beijing-Guangzhou HSR in China.

The train operation plan should be rescheduled in the bottleneck section for a better capacity utilization, taking the passenger demand and the cooperation with the whole train operation into account. Reference to the compress timetable method in UIC 406, a train rescheduled model is established, with an objective to minimize the occupancy time of trains in the bottleneck section, considering headway constraints, dwelling time constraints, interstation travel time constraints and so on. Then a precise algorithm called Branch and Bound Algorithm is used to solve to model.

**Extending UIC 406-based capacity analysis - New approaches for railway nodes and network effects**

Norman Weik, Jennifer Warg, Ingrid Johansson, Nils Nießen and Markus Bohlin

Railway capacity planning aims to determine the amount of traffic that can be operated on a given infrastructure. The timetable compression method described in UIC Code 406 has become one of the standard tools in this area. Motivated by the Swedish Transportation Administration's timetable independent adaptation of the methodology and its need for extension we explore how the compression method can be applied to evaluate the capacity of the underlying infrastructure for strategic planning rather than the occupation ratio of a specific timetable. By performing ensemble averaging of scheduled train sequences we abstract from a single timetable concept and perform a distributional analysis of timetable utilization. The methodology is applied in capacity assessment of railway stations and line segments. To mitigate decomposition-induced underestimation of network effects the compression area is extended and approaches to include interdependencies between stations and lines are investigated. The methodology is tested in a case study based on data from the Swedish Southern Mainline rail corridor.

**Estimating the Capacity of Railway Lines Considering EMU Circulation: A Lagrangian Decomposition-based Approach**

Zhengwen Liao, Jianrui Miao, Ying Wang, Haiying Li and Francesco Corman

Railway capacity is subject to various conditions, such as the minimum headways, the number of platforms and the number of rolling stocks and crews. This paper extends the railway capacity estimation problem by considering the electrical multiple unit (EMU) circulation. A MIP model based on a hybrid time-space-state network is applied to optimize the capacity utilization with the objective function of maximizing the number of desired trains. To overcoming the computation difficulties on a very large scale problem, a Lagrangian relaxation-based approach is proposed. This decomposes the model into timetabling sub-problem and EMU circulation sub-problem by dualizing the consistency constraints. We use the data of...
Beijing to Tianjin intercity railway to show the effectiveness of the approach. The experimental result shows that the total throughput of the railway system depends on either the infrastructure capacity or the EMU circulation according to different fleet sizes. A multi-objective Pareto analysis is conducted for analyzing the trade-off between different type of trains. The benefit of the decomposition solution approach is displayed by the performance comparison with the centralized and sequential method.

SESSION 4C: 11:10-12:30 TIMETABLING 1
Applying Geometric Thick Paths to Compute the Maximum Number of Additional Train Paths in a Railway Timetable
Anders Peterson, Valentin Polishchuk and Christiane Schmidt

Railway timetabling is a prominent research area in railway research. The time table is usually shown as a time-space diagram. However, even algorithms that try to adapt/add to an existing timetable rely on mixed integer programming, on graph theory etc., but do not use the geometric representation of the time table. In this paper, we consider the problem of determining residual train paths (e.g., for freight trains) in an existing time table close to operation. We aim to restrict possible disturbance on existing (passenger) traffic, and, hence, insert train paths of a specified minimum temporal distance to other trains. We show how we can use algorithms for thick paths in polygonal domains to compute the maximum number of trains with a specified robustness to insert.

A novel timetabling procedure which considers running speed of trains and its application to actual cases
Yasufumi Ochiai and Norio Tomii

In railway lines in which both rapid trains and regular trains have to be operated and the frequency is very high, rapid trains inevitably have too much running time supplement. This means drivers of rapid trains have too much freedom in driving. Thus, if drivers of rapid trains do not run the train “properly,” delays occur for the train or for the succeeding train. Hence, in order to realize high punctuality, rapid trains must run so that they do not stop nor do not give an influence to the succeeding train, which is almost impossible if no information is given. In this paper, we propose an idea to specify not only arrival and departure times but running speed of rapid trains at critical sections in a timetable to make the train operation more punctual. In order to realize this idea, we settled two issues. One is to establish a method to decide the location and the running speed there in the timetabling process. The other is to implement a system which shows the speed information to drivers in an economical way. We have applied this approach when we revised our timetable in March 2018 and from the analysis of the historical train traffic data for several months, we have confirmed that the delays were greatly reduced and our approach was very successful.

Delay Prediction with Flexible Train Order in a MILP Simulation-Optimization Approach for Railway Timetabling
Johan Högdahl

This paper considers the problem of minimizing travel times and maximizing travel time reliability, which are important socio-economic properties of a railway transport service, for a
given set of departures on a double-track line. In this paper travel time reliability is measured as the average delay, and a delay prediction model for MILP timetable optimization is presented. The average delay prediction model takes into consideration time supplements, buffer times and propagation of delays in the railway network and is not restricted to a fixed order of the trains. Validation of the average delay prediction model, and an evaluation of the approach with combined simulation-optimization for improving railway timetables, are conducted by a simulation study on a part of the Swedish Southern Main Line. Results from the simulation study show that the average delays are reduced by up to approximately 40% and that the punctuality is improved by up to approximately 8%.

The comparison of three strategies in capacity-oriented cyclic timetabling for high-speed railway
Xin Zhang, Lei Nie and Yu Ke

The expansion of the scale of high-speed railway networks and the growth of passenger demand imply a high frequency of high-speed trains in China, i.e. higher railway capacity utilization. Based on given infrastructures and train line plans, there are some timetabling strategies which affect the capacity utilization, e.g. changing train departure sequence at origin stations, overtakings between trains, and adding new train stop at stations. Nowadays, managers of high-speed railway in China are eager to find out that what kind of impact these strategies have on the capacity utilization. In this study, new variables of train stops and constraints of overtakings are proposed with an extended cyclic timetabling model based on the periodic event scheduling problem (PESP). Minimum cycle time, train travel time and the total number of train stops are calculated as objectives to measure the differences between the strategies. The effectiveness of the three timetabling strategies are compared and presented by a series of experiments based on one real-world rail line in China. According to our results, with flexible train departure sequence at the origin stations and train overtakings, the possibility of acquiring good capacity utilization can be higher, but too many overtakings will have negative effect on the quality of timetable. The effectiveness of adding new stops on the capacity utilization depends on the ways of adding stops, i.e. which train is allowed to be added new stops and which stations can be selected to stop at.

SESSION 4D: 11:10-12:30 NETWORK AND LINE PLANNING 1

Simulation of metro operations on the expanded Blue line in Stockholm
Hans Sipilä and Anders Lindfeldt

Stockholm’s Metro is about to be expanded. Nearly twenty kilometres of new track and eleven new stations on four sections. The construction is planned to start in 2018/2019.

The purpose of this study was to evaluate the metro system performance for two different timetable scenarios. At the same time it should be evaluated if there was any significant impact on the simulation results whether Sofia station, where trains from different branch lines merges, is designed with two or three platform tracks.

Simulations were performed in RailSys with distributions prepared from log data regarding run times, dwell times and deviation from scheduled departure times. In order to fully model the
signaling system behavior and setup regarding the tracks vertical profile around Sofia station a model was developed for this.

The results concluded that there could not be observed any significant effect on the expected delays during normal operations whether Sofia station consisted of two or three platform tracks.

**Optimal Train Service Design in Urban Rail Transit Line with Considerations of Short-Turn Service and Train Size**

*Zhengyang Li, Jun Zhao and Qiyuan Peng*

The train service scheme of an urban rail transit line specifies information such as the total number of train services operated in the line, and the associated turn-back stations, train size and frequency of each service. A reasonable train service scheme can provide satisfactory services for passengers and reduce the operational cost for operators. This paper focuses on the optimal train service design problem in an urban transit line, where both the short-turn services and the train size of each service are considered. A service network based on a given pool of candidate train services with provided turn-back stations is constructed. The optimal strategy is used to assign passenger flows on the service network so as to describe the transfer process of passengers between different train services. Considering many operational and capacity constraints, a mixed integer nonlinear programming model minimizing the sum of the operators’ cost and passengers’ waiting time cost is developed to identify train services from the service pool and determine the train size and frequency of each chosen service. The nonlinear model is transformed into a linear one, and two simplification methods named service network simplification and OD pair aggregation are proposed to improve further the computational efficiency of the model. Finally, realistic instances from Chongqing Rapid Rail Transit Line 26 in China are used to test the proposed approaches. The results show that our approach can effectively reduce the operators’ cost and the passengers’ waiting time cost compared with the empirical method frequently used in practice.

**An Iterative Approach for Profit-Oriented Railway Line Planning**

*Di Liu, Pieter Vansteenwegen, Gongyuan Lu and Qiyuan Peng*

With the rapid development of the Chinese high-speed railway (HSR) network, more and more railway lines are becoming oversaturated, leading to inefficient operations and reducing the service quality. To improve the network’s performance, this paper proposes a profit-oriented line planning model for collaboratively optimizing the operational costs and passenger travel times. Due to the complexity of the problem, an iterative approach is designed to solve the problem efficiently. Two case studies are implemented to verify the performance of the approach. The results of the small example show that the best found line plan can save up to 6% of the travel time compared to the initial solution and improve the profit with 2%. The proposed iterative approach also performs well in searching for high-quality solutions on the large railway network.

**Multi Objective Optimization of Multimodal Two-Way Roundtrip Journeys**

*Felix Gündling, Pablo Hoch and Karsten Weihe*
Multi modal journeys often involve two trips: one outgoing and one return trip, as in many cases, the traveller would like to return to his starting point. If a car or bike was used in combination with public transportation (i.e. park & ride), this introduces a dependency between outward and return trip: both must include the same parking place. Optimizing both trips independently may yield suboptimal results. We consider the multi modal two-way roundtrip problem and propose several algorithms. All proposed algorithms compute journeys that are optimal regarding multiple criteria. Our study with realistic scenarios based on real data shows promising results.

SESSION 5A: 13:30-14:30 DELAY ANALYSIS AND PREDICTION 1
Modelling the Influences of Primary Delays Based on High-speed Train Operation Records
Zhongcan Li, Ping Huang, Chao Wen and Yixiong Tang

Primary delays (PDs) are the driving force of delay propagation. Hence, accurate predictions of the number of affected trains (NATs) and the total time of affected trains (TTATs) due to PDs can provide a theoretical background for the dispatch of trains in real time. Train operation data were obtained from Wuhan-Guangzhou High-Speed Railway (HSR) station from 2015 to 2016, and the NAT and TTAT influence factors were determined after analyzing the PD propagation mechanism. The NAT predictive model was established using eXtreme Gradient Boosting (XGBOOST) algorithm which was more efficient than other machine learning methods after comparison. Furthermore, the TTAT predictive model was established based on the NAT model using the support vector regression (SVR) algorithm. The results indicate that the XGBOOST algorithm has good performance on the NAT predictive model, whereas SVR is the best method for the TTAT model using Lessthan5 variable, which is the ratio of the difference between the sample size of actual and the predicted values in less than 5 min and the total sample size. In addition, 2018 data were used to evaluate the application of NAT and TTAT models over time. The results indicate that NAT and TTAT models have a good application over time.

Markov Chain Model for Delay Prediction of Trains
Ismail Sahin

In our previous work a Markov chain model for the stochastic process of train delays at stations was presented (Şahin, 2017). The model proposed a method for developing the stochastic one-step transition matrices for the running time delays (for recovery) and the conflict resolution delays (for deterioration) using the real-life train operation data. It is possible to estimate the delay distributions at stations under the effects of running time supplements and buffer times. Hence, the model can be used to evaluate the effectiveness of the time supplements embedded into the train schedules, in addition to some other performance measures. In this current investigation, the use of the stochastic matrices is expanded to predict train delay states at the stations ahead along the train path. We investigate the effects of the recovery and deterioration transition matrices developed in combination with the current delay state of a particular train in order to predict its expected time of arrival at subsequent stations. The recovery and deterioration matrices are used in the prediction repeatedly (as many times as needed) whenever a new prediction is made. The former matrix is considered in the prediction when a train run occurs and the latter one is considered when a train is expected to interfere with another train. In addition to the delay and trajectory prediction, the model can also be
used to trace delay propagation and to measure schedule robustness. The goodness of the model predictions is assessed against the real-life data for train movements.

**Long-short Memory Neural Network for Short-term High-speed Rail Passenger Flow Forecasting**

*Yang Yang Zhao and Xinguo Jiang*

The uncertainty of estimating the railway passenger flow in advance may disrupt the passenger operation and management (e.g., passenger evacuation planning, seat allocation, and train timetable programming). In order to proactively improve the service quality and efficiency of the railway system, the short-term passenger flow prediction technique is vital in the field of operation and management system. Utilizing the deep learning library-keras, the study develops a Long short-term memory neural network (LSTM NN) to predict the short-term high-speed rail (HSR) passenger flow. Processing the raw data, we first construct the passenger flow sequences as the input (output) variables. Then the grid search and cross validation techniques are applied to optimize the LSTM NN parameters. At last we utilize the data provided by Shanghai railway administration of China as the case study. Through a comparison with other representative methods, including Auto-Regressive Integrated Moving Average (ARIMA), Back Propagation Neural Network (BPNN), and Support Vector Machine Regression (SVR), results suggest that the proposed LSTM NN can generate great potentials for accurate passenger flow predictions.

**SESSION 5B: 13:30-14:30 ROLLING STOCK SCHEDULING AND MAINTENANCE 1**

*Train Unit Shunting : Integrating rolling stock maintenance and capacity management in passenger railway stations*

*Franck Kamenga, Paola Pellegrini, Joaquin Rodriguez, Boubekeur Merabet and Bertrand Houzel*

In passenger railway stations, train units preparation is crucial for service quality. This preparation includes maintenance check, cleaning, coupling and uncoupling. Such operations require parking train units on shunting yards located close to platforms. Therefore trains have to be moved between platform and shunting tracks. Taking over train units between their arrival and their departure in a station constitutes shunting. The Generalized Train Unit Shunting problem (G-TUSP) is the problem of shunting operations planning. The problem is to assign arriving train units to departing train units, shunting tracks and paths, to schedule shunting movements and to assign crews to maintenance operations. The aim of the paper is to provide an algorithmic approach for the G-TUSP. The contribution presents an integrated problem with a mixed-integer linear programming (MILP) formulation. The formulation is based on a microscopic model of the infrastructure and formal train units in order to consider coupling and uncoupling. The model is solved exactly using the commercial solver CPLEX. It is tested on instances based on Metz-Ville station in France. The results are promising and show the suitability of the model.

*A Mixed Integer Linear Programming Approach to a Rolling Stock Rostering Problem with Splitting and Combining*

*Satoshi Kato, Naoto Fukumura, Susumu Morito, Koichi Goto and Narumi Nakamura*

Railway operators must schedule resources such as rolling stock and crew in order to operate trains as defined by a timetable. This paper considers scheduling of rolling stock, which is
usually done by creating a roster. A roster is a series of trains to be performed by the particular rolling stock. The number of train-sets required to operate a given group of trains is essentially determined by the roster and generation of an efficient roster is essential. Important considerations of the roster generation include maintenance such as pre-departure inspection. On some lines in Japan, splitting and combining are often used to adjust transportation capacity flexibly. Under this type of operation, splitting and combining become necessary. These shunting operations require time and manpower, so it is necessary to reduce the amount of splitting and combining. This paper presents a mixed integer linear programming model so that the amount of splitting and combining is reduced together with the roster length and the distance of empty runs. Results of computational studies will be presented based on real instances of several lines in Japan, indicating the computational effectiveness of the methodology and with respect to the reasonableness of the resultant rosters.

Reducing the Adaptation Costs of a Rolling Stock Schedule with Adaptive Solution: the Case of Demand Changes
Rémi Lucas, Zacharie Ales, Sourour Elloumi and François Ramond

In railway scheduling, a nominal traffic schedule is established well in advance for the main resources: train-paths, rolling stock and crew. However, it has to be adapted each time a change in the input data occurs. In this paper, we focus on the costs in the adaptation phase. We introduce the concept of adaptive nominal solution which minimizes adaptation costs with respect to a given set of potential changes. We illustrate this framework with the rolling stock scheduling problem with scenarios corresponding to increasing demand in terms of rolling stock units. We define adaptation costs for a rolling stock schedule and propose two MILPs. The first one adapts, at minimal cost, an existing rolling stock schedule with respect to a given scenario. The second MILP considers a set of given scenarios and computes an adaptive nominal rolling stock schedule together with an adapted solution to each scenario, again while minimizing adaptation costs. We illustrate our models with computational experiments on realistic SNCF instances.

SESSION 5C: 13:30-14:30 PASSENGER FLOW ANALYSIS 1
Passenger Flow Control with Multi-station Coordination on an Oversaturated Urban Rail Transit Line: A Multi-objective Mixed-integer Linear Programming Approach
Denghui Li, Qiyuan Peng and Gongyuan Lu

With the booming travel demands in the urban cities, which can’t be satisfied due to the limited transportation capacity in urban rail transit, passenger congestion problem become increasingly serious, causing the potential accident risks on platforms. To further efficiently improve the conditions, this paper proposes an effective collaborative optimization method for the accurate passenger flow control strategies on an oversaturated urban rail transit line by simultaneously adjusting the number of inbound passengers entering multiple stations on the line. Through considering the space-time dynamic characteristics of passenger flow, a multi-objective mixed-integer linear programming model is formulated to firstly minimize the number of passengers who are limited to enter stations, secondly minimize the total passenger waiting time on platforms at all of involved stations where the optimal passenger flow control is imposed to avoid congestion on platforms within the transportation capacities, and thirdly maximize the passenger person-kilometres. Due to a small scale of the model, it can be solved
by CPLEX solver efficiently. Moreover, because the passenger flow demand is time-variant, it’s very necessary for an accurate and easy-to-implement passenger flow control strategy to determinate the control time intervals. Hence, in order to get an optimal determination of the control time intervals, Fisher optimal division method is firstly applied after modelling. Finally, two sets of numerical experiments, including a small-scale case and a real-world instance with operation data of Chengdu metro system, are implemented to demonstrate the performance and effectiveness of the proposed approach.

**Machine Learning based integrated pedestrian facilities planning and staff assignment problem in transfer stations**

*Bisheng He, Hongxiang Zhang, Keyu Wen and Gongyuan Lu*

Optimizing the pedestrian facilities plan in transfer stations is the problem of adjusting the facilities on the layout of pedestrian flow route and the number of machines in service to service to meet the level of services requirements. In the practice, the operation of pedestrian facilities plan is always associated with the staff assignment. Hence, we develop a machine learning based integrated pedestrian facilities planning and staff assignment optimization model in transfer stations to schedule the pedestrian facilities plan and the staff assignment together. It aims to minimize the staff assignment cost and the deviation of working time of each employee of the station. The minimizing of the deviation gains the fairness of the assignment plan. The facilities plan is enforced by the level-of-services requirement in three performance indicators including transfer capacity, transfer average time and level-of-service. The performance indicators of facilities plans are evaluated by a simulation-based machine learning method. Based on simulation results, the random forest method fits a quantitative relationship among performance indicators of the facilities plans with operation scenario attributes and facilities plan attributes. The experiments on the case study of Xipu station show the integrated model can return pedestrian facilities plans which meet the level of service requirements and assign employees fairly of each period in a day and minimize the labor cost. The solutions of pedestrian facilities plan and staff assignment plan for possible operation scenarios in future are also suggested to station manager by our integrated method.

**Trial approach of station congestion estimation**

*Toru Sahara*

We built a test tool to estimate and visualize the congestion of the station. We utilized only existing data, we didn’t install new sensors. Since it is a test tool this time, we do not actually expect congestion in real time. We gathered past data and verified whether it was predictable or not.

In this tool, we estimated by loading weight data, delay data, and ticket gate data. From these data, we calculated congestion at each place of the station. Since the data that can be acquired in real time is only the loading weight data and the delay data, regarding ticket gate data, we estimated real time congestion based on past data.

Since this research is in its early stages, we selected two stations that are easy to estimate. At these stations, we divided the areas by platforms, stairs, and concourses and made an estimate.
Regarding the display method of the estimation result, we displayed three-level display by color, in addition to displaying the congestion by the numerical value. By displaying in color, dispatchers can easily identify congestion.

First, we verified accuracy of the numerical value. We verified the error of estimation using MAPE, which is an indicator for evaluating magnitude of error. We found an error of 10% to 60%. In the calculation method of MAPE, errors become large as the number of people is small. With this level of error, we can use the tool for business use.

**SESSION 5D: 13:30-14:30 FREIGHT TRAFFIC PLANNING 1**

**Autonomous Freight Trains in Australia**

*Alex Wardrop*

Australia’s first autonomous train began running in July 2018. Its running was preceded by extensive trials of both on- and off-train technology. It was not a classic metro train but a 30,000+ tonnes bulk iron ore train, comprising 220-240 wagons, each weighing 130-160 tonnes when laden, and hauled by 2x3280 kW diesel locomotives. This paper discusses the usual rationales for developing autonomous trains and then tests them against the realities of running heavy haul freight trains in remote areas. Any apparent lack of line capacity is less important than the need for reliable mine-to-port supply chains. Furthermore, mining in remote areas is expensive and increasingly difficult to resource so automation of processes is increasingly attractive to mining companies. The automation of iron ore railway operations beckoned if mining companies could assemble, test and have accepted the various technical building blocks. Pilbara Iron has now completed these steps.

**A Railway Network Design Model for the Joint Expansion and Improvement of Freight Railway Infrastructures**

*Francisca Rosell and Esteve Codina*

The increasing movement of goods in Europe due to the globalization and the rapid rise of e-commerce is a huge challenge for the governments, which have to deal with congestion on the roads and environmental pollution. Using train for freight transportation can help to tackle both problems: because of its high loading capacity and because in Europe, railway networks are mainly electrified. However, freight transportation by rail in Europe is much reduced when compared to road transportation. As a consequence, the European authorities try to improve rail infrastructures and connectivity, to increase the efficiency of rail transport and also to increase its share in the European transport market to decongest roads and to reduce pollutant emissions.

In this paper, a mathematical programming-based model is presented for assessing a capacity expansion problem on a railway network. In this model, the authors have considered extensions of elements of an existent freight railway network, jointly with actions on the network with relative smaller cost, such as the inclusion of new sidings or new gauges in several rail segments, expansion of classification terminals or stations, and also capacity enhancements by new blocking/control systems. These aspects are usually not taken into account in models for regional planning. Our approach, rather than a model of railway capacity expansion can be considered a mixture of capacity-expansion with network design. The model is tested on a small
regional network of the Mediterranean Corridor, and the computational results show its applicability to larger networks.

**Locomotive rotation optimization as basis for efficient rail cargo operation**  
*Thomas Albrecht* and *Jonatan Gjerdrum*

To remain competitive in the competition on the cargo market, railway undertakings need to execute operations with high efficiency. IT systems can contribute to determine the actual boundaries of the use of available production resources and operate optimally close to these bounds.

Mathematical optimization and automation are key factors to realize this, e.g. in the field of Locomotive rotation planning. This contribution describes different approaches that have been implemented in the Locomotive Optimization System LOOP which has been developed by DXC Technology in close cooperation with Green Cargo – the largest rail cargo operator in Sweden.

The main purpose of the system is to create plans for template weeks of cyclic planning (e.g. for simulation studies on the procurement of locomotives of different type) and dated monthly plans for short term planning. Different mathematical models are used to consider the various aspects of the objective function, e.g. number of locomotives used, operational efficiency and penalisation of loco changes in multiple traction. The consideration of conditions imposed by surrounding planning problems (e.g. crew, wagon transport) has been one of the biggest challenges in the project. The resulting mixed integer linear programming models are solved by commercial solver (CPLEX). The planners work in a web-based user interface, which is based on DXCs Rail Cargo Management Solution used by more than 20 customers throughout Europe.

The close cooperation between the railway operator and the IT solution provider resulted in a solution which allows building plans in shorter time than previously and saving locomotives.

**SESSION 6A: 14:40-15:40 TIMETABLING 2**

**Improving transfer quality of the air and high-speed rail integration service via adjusting a rail timetable: A real-world case study in China**  
*Yu Ke*, *Lei Nie*, *Wuyang Yuan* and *Xin Zhang*

Air and high-speed rail (AH) integration services are gaining ground with the development of the high-speed railway and the airline industry. A well-designed feeder train timetable with good transfer quality in the AH integration service is of great significance, especially when train frequencies are low in a transfer node. To assess the transfer quality, we classify the transfers based on the transfer time. In this study, a bi-objective train timetabling model is proposed to maximize the quality of transfers from trains to flights and minimize the deviation from the original official timetable in the AH integration service. By optimizing the two objectives independently in two stages, a heuristic algorithm is developed to solve the proposed model. In the first stage, the first objective is optimized; in the second stage, the timetable shift is minimized by the rolling horizon approach with the transfer quality fixed. The method is applied to Shijiazhuang Zhengding International Airport, China. The result indicates that the proposed model is effective in improving the transfer quality and decreasing the timetable shift, and some analysis of solution are presented to verify the efficiency of the suggested model.

**Transforming automatic scheduling in a working application for a railway infrastructure manager**
In this article, we present a practical approach for the optimized creation of railway timetables. The algorithms are intended to be used by Deutsche Bahn, Germany’s largest railway infrastructure provider. We show how our methods can be used, both for creating a timetable in advance and for answering ad-hoc requests coming in via a digital app. Numerical experiments are provided to show that our solution exceeds manual timetabling in terms of capacity usage, travel times and the time taken for creating the timetable.

**Timetable quality from the perspective of an infrastructure manager in a deregulated market: a case study of Sweden**

*Sara Gestrelius, Anders Peterson and Martin Aronsson*

There are many stakeholders when it comes to railway timetable planning, e.g. infrastructure managers, railway undertakings and train passengers. This paper analyses timetable quality from the perspective of the Swedish infrastructure manager, i.e. from the perspective of an infrastructure manager operating in a deregulated market. Seven categories of timetable quality are discussed: feasibility, disturbance resistance, competition management, capacity safeguarding, application fulfilment, attractiveness and compatibility with surrounding planning areas. Each category is introduced, including references to legal documents, current development projects and research literature. Further, an interview study with eight practitioners gives insight into the current state of practice in Sweden. The practitioners consider feasibility to be both most important and easiest to handle. Capacity guarding is considered least important, despite its prevalence in legal documents and envisioned process developments, and is also considered hardest to handle. The lack of published guidelines was repeatedly mentioned as an explanation to why capacity guarding is not considered during timetable construction. In general, formal rules and guidelines seem important for supporting the timetable planners in their arbitrating role, and improved timetable planning tools would also be beneficial for resolving e.g. problems with maintenance possession planning. The results show that there is a gap between the wanted state as depicted by legal documents and development projects, and the current state of practice in Sweden. Operational research can contribute to closing this gap, both by constructing formal guidelines and measurements for quality aspects, and by developing functionalities for timetable planning support tools.

**SESSION 6B: 14:40-15:40 ENERGY SAVING 1**

**Energy savings with enhanced static timetable information for train driver**

*Thomas Graffagnino, Roland Schäfer, Matthias Tuchschmid and Marco Weibel*

On the network of the Swiss Federal Railways (SBB) there is huge variability in the energy consumption for comparable train runs. Consequently, there is a significant potential to achieve energy savings with improved driving strategy, which can be influenced by providing useful information to the train driver. As part of the smartrail programme operated by the Swiss railway industry, several energy savings measures are due to be implemented. As a first step in the smartrail energy measures, SBB conducted a pilot test in summer 2018. This pilot involved 473 test runs on two important passenger trains in Switzerland: the long-distance train IC8 and the local train S12 from Zurich. For each train run, based on effective routing, train composition,
speed restrictions and timetable fixed points, a speed profile and new service times for each station were calculated early each morning for all the train runs of the day.

More than 80% of the regular train drivers would welcome the rollout of the new timetable information soon. A comparison of the accompanied journeys against the ‘baseline’ (same trains in the same period) shows a significant reduction in energy consumption without affecting punctuality: depending on the train journey, the accompanied runs consumed between 1.4% and 13.3% less energy per gross tonne-kilometre.

The high levels of acceptance by the train drivers combined with the significant energy savings achieved without affecting punctuality is very promising. For this reason, a system-wide rollout is currently being investigated and could be started by late 2019.

A Method of Generating Energy-efficient Train Timetable Including Charging Strategy for Catenary-free Railways with Battery Trains
Takuya Sato and Masafumi Miyatake

Catenary-free transportation system is in development and has been installed in several countries. Battery train is used as the train which can travel in catenary-free section using power supplied from an onboard storage system such as lithium-ion battery. However, as characteristics of this type of train, an energy consumption of battery train depends on the state of energy of the storage system. Furthermore, battery train needs rapid charging when running the long distance. Hence, energy efficient design of catenary-free transportation system is important. In consideration of these characteristics, in this research, we propose a generation method of the timetable including running time, dwell time and location of charging infrastructure which is the most energy-saving for catenary-free transportation system with battery trains. Firstly, we conduct a running simulation and reveal the relationship among running time, state of charge of the battery and energy consumption. The characteristic is derived as a two-variable function and nonlinear for each variable. Although this optimization problem can be defined as a nonlinear programming problem, we ease to solve this problem using linear approximation to the energy consumption characteristic. Specifically, we use a method of dividing the characteristic defined on the space as curved surfaces into fine lattice shapes and approximating it as a polyhedron composed of minute triangles. In the end, we carried out a simulation in a simple case so that we can show the effect of the proposed method.

Optimal running time supplement distribution for energy-efficient train control
Gerben Scheepmaker, Peter Pudney, Amie Albrecht, Rob Goverde and Phil Howlett

Energy efficiency is an important topic for railway companies wishing to reduce CO2 emissions and save money. One of the research areas to improve the energy efficiency of railways is energy-efficient train control (EETC). EETC is an optimal control problem with the aim of finding the driving strategy or trajectory that meets the timetable with the least amount of energy consumption. The potential for EETC is determined by the timetable, because the running time supplements determine how much energy can be saved by energy-efficient driving. Therefore, in this paper we focus on the optimal distribution of running time supplements for the energy-efficient driving of a single train over multiple stops. Furthermore, we compare an indirect solution method to a direct solution method to solve the EETC problem, and apply the two methods to different case studies to find the optimal distribution of running time supplements.
to achieve the most energy-efficient driving. The indirect method is used by the Energymiser Driver Advice Systems. Direct solutions are found using the Radau Pseudospectral Method. The results of the direct solution method confirm the optimality conditions used by the indirect method and also confirm that the optimal cruising speed is the same over multiple sections.

SESSION 6C: 14:40-15:40 PASSENGER FLOW ANALYSIS 2
Dynamic Origin-Destination-Matrix Estimation for Commuter Train Planning Using Smart Cards
Abderrahman Ait-Ali and Jonas Eliasson

Problems of dynamic origin-destination, hereafter OD, matrix estimation using smart card data can be modelled as entropy maximization problems and efficiently solved using solution techniques such as Lagrangian relaxation.
In this paper, we briefly review the literature of OD-matrix estimation and the use of smart card data. We show how this problem can be modelled and solved with incomplete smart card data where the trip distribution incoming to stations is known but not the outgoing distribution. A large non-linear entropy maximization problem is solved using an iterative algorithm solution based on Lagrangian relaxation.
The algorithm is tested using a case study from the commuter train service in the great Stockholm region. Even though there are no theoretical guarantees for the algorithm's convergence, the results show that with the incomplete smart card data, the solution method converges and finds an estimate of the dynamic OD-matrix reflecting the reported aggregate statistics from the local operator.

Passenger Flow Prediction of High Speed Railway Based on LSTM Deep Neural Network
Jie Li, Ping Huang, Yuxiang Yang and Qiuyan Peng

The paper presents the characteristics of the departing passenger flow in different stations based on the real-record passenger flow data of Beijing-Guangzhou high speed railway, from January, 2010 to December, 2015. The passenger dataset is framed for the long short-term memory (LSTM) model, considering the expectation input format of LSTM layers and the characteristics of the data. The Keras model in Python is used to fit LSTM model with tuning and regulating all the parameters necessary in the model. Then the fitted LSTM model is applied to forecast the short-term departing passenger flow of Beijing-Guangzhou high speed railway. The influence of important parameters in the LSTM model on the prediction accuracy is analyzed, and the comparison with other representative passenger flow forecast models is conducted. The results show that the LSTM model can get the valid information in a long passenger flow time series and achieve a better performance than other models. The passenger flow prediction errors valued by MAPE are 7.36%, 7.33%, 8.03%, respectively for Chenzhou station, Hengyang station and Shaoguan station. The parameters in the LSTM model such as the number of neurons, the input historical data length and the size of output layer have a great influence on the prediction accuracy.

Methods for quantitative assessment of passenger flow influence on train dwell time in dense traffic areas
Sélim Cornet, Christine Buisson, François Ramond, Paul Bouvarel and Joaquin Rodriguez
Railway operations in dense traffic areas are very sensitive even to small disturbances, and thus require careful planning and real-time management. Dwell times in stations are in particular subject to a high variability and are hard to predict; this is mostly due to the interactions between passengers and the system during the dwelling process. This paper proposes an approach for estimating the minimum dwell time knowing the numbers of alighting, boarding and on board passengers, using Automatic Vehicle Location and Automatic Passenger Counting data. Based on the knowledge of this value, a method for estimating the conditional distribution of dwell time given passenger flows is presented. Numerical experiments are carried out on two stations located inside the dense traffic area of Paris suburban network. The obtained results show a broad applicability of these methods, that hence seem very promising.

**SESSION 6D: 14:40-15:40 CAPACITY ANALYSIS 2**

**Punctuality and Capacity in Railway Investment: A Socio-Economic Assessment for Finland**
Luca Corolli, Giorgio Medeossi, Saara Haapala, Jukka-Pekka Pitkänen, Tuomo Lapp, Aki Mankki and Alex Landex

The impact of rail network improvements on capacity and rail traffic punctuality in socio-economic analyses currently lacks an established quantitative method. This paper presents a professional research conducted for the Finnish Transport Agency aimed at the development of methods to evaluate such impacts. Two methods are proposed. The first is aimed at capacity estimation, and is an adaptation of the UIC 406 method to the characteristics of the Finnish rail network. The second is a method based on mathematical regression that allows estimating delays on lines given a set of parameters describing their characteristics. The delay estimation method proposes two distinct formulas for single- and double-track lines. The proposed methods were studied both on Finnish actual data and on a UK scenario. The use of these methods enables network managers to evaluate both network saturation and the effect of investments on delays in a simple way. This study has been approved and adopted by the Finnish Transport Agency.

**Tactical Capacity Assessment of a High-speed Railway Corridor with High Heterogeneity**
Yanan Li, Ruihua Xu, Chen Ji, Han Wang and Di Wu

Capacity assessment of high-speed railway corridor is critical in tactical planning process because it is beneficial to unearth the potential capacity and improve the capacity utilization without new investment in construction. China’s high-speed railway corridor serves trains with high heterogeneity in different route, speed, and stopping plans. This paper first illustrates the necessity of assessing the corridor’s capacity as a whole without decomposition. Based on the concept of base train equivalent (BTE), two methods named “capacity occupancy equivalent (COE)” method and “demand adaptation equivalent (DAE)” method are developed to standardize different types of trains into an equivalent unit. The case study of Jing-Hu high-speed railway corridor demonstrates that the methodology is concise in capacity assessment, and the impact of the long-distance direct service on corridor capacity utilization is also calculated.

**Modelling the Prohibition of Train Crossings in Tunnels with Blocking Time Theory**
Wiebke Lenze and Nils Nießen
Preventing passenger and freight trains from crossing each other in double-track rail-way tunnels is a fire safety measure required by the German railway authority to prevent fatal accidents. The prohibition poses a restriction on infrastructure usage that has to be incorporated in rail traffic planning. While it has already been implemented in timetabling and simulation tools, its effects on line capacity in long-term strategic planning has not been investigated so far. This paper presents a method to incorporate restrictions on simultaneous track usage in the blocking time calculation and minimum headway time estimation. The effects on line capacity are analysed quantitatively based on the STRELE approach, which is an analytical method for strategic long-term capacity planning currently used by German railway infrastructure manager DB Netz AG. Results are validated by comparison to delay increase in microscopic simulation of train operations.

SESSION 7A: 16:10-17:30 TRAFFIC MANAGEMENT 2

A new Constraint Based Scheduling model for real-time Railway Traffic Management Problem using conditional Time-Intervals
Grégory Marlière, Sonia Sobieraj Richard, Paola Pellegrini and Joaquin Rodriguez

This paper tackles the real-time Railway Traffic Management Problem (rtRTMP) of finding an optimal choice for the train schedules and routes to reduce the delays of trains due to unavoidable conflicts. We present a new formulation of the rtRTMP. This new formulation is based on a previously proposed one that models railway traffic at a microscopic level with optional activities using a Constraint Based Scheduling (CBS) approach. To ease the modelling of optional activities, a new concept based on a tree data structure and a specific filtering algorithm was extended by the introduction of conditional time-interval variables in CP Optimizer library. The new formulation of the rtRTMP presented in this paper exploits the conditional time-interval variables. The formulation has been validated with experiments on a large set of instances. The experimental results demonstrate the effectiveness of this new CBS model and show good performance of the proposed approach compared with the state-of-the-art RECIFE-MILP algorithm.

Train Rescheduling for an Urban Rail Transit Line under Disruptions
Y. Chang, R. Niu, Y. Wang, X. Luan, A. D’Ariano and M. Samà

Disruptions in urban rail transit systems usually result in serious incidents because of the high density and the less flexibility. In this paper, we propose a novel mathematical model for handling a complete blockage of the double tracks for 5-10 minutes in the peak hours, e.g., lack of power at a station, no train can pass this area during the disruption. Under this operating scenario, train services may be delayed or cancelled, some rolling stocks may be short-turned at the intermediate stations with either single or double crossovers. To ensure the service quality provided to passengers, the backup rolling stocks inside the depot may also be put into the operation depending on the consequences of the disruptions. Thus, the number of rolling stocks in the depot is considered. We discuss the disruption management problem for urban rail transit systems at a macroscopic level. However, operational constraints for the turnaround operation of rolling stocks and for the rolling stock circulation are modelled. A mixed integer linear programming (MILP) model is proposed to minimize the train delays and the number of canceled train services as well as to ensure a regular service for passengers, while adhering to the departure and arrival constraints, headway constraints, turnaround constraints, service
connection constraints, inventory constraints, and other relevant railway constraints. Existing MILP solvers, e.g. CPLEX, are adopted to compute near-optimal solutions. Numerical experiments are conducted based on real-world data generated for Beijing subway line 7 to evaluate the effectiveness and efficiency of the proposed model.

Exploring the potential of GPU computing in Train Rescheduling
Sai Prashanth Josyula, Johanna Törnquist Krasemann and Lars Lundberg

One of the crucial factors in achieving a high punctuality in railway traffic systems, is the ability to effectively reschedule the trains during disturbances. Railway rescheduling is a complex problem to solve both from a practical and a computational perspective. Problems of practically relevant sizes have typically a very large search space, making it a challenge to arrive at the best possible solution within the available computational time limit. Though competitive algorithmic approaches are a widespread topic of research, not much research has been done to explore the opportunities and challenges in parallelizing them on Graphics processing units (GPUs). This paper presents a conflict detection module for railway rescheduling, which performs its computations on the GPU. The aim of the module is to improve the speed of solution space navigation and thus the solution quality within the computational time limit. The implemented algorithm proved to be more than twice as fast as the sequential algorithm. We conclude that for the problem under consideration, using a GPU for conflict detection likely gives rise to better solutions at the end of the computational time limit.

Studies on the validity of the fixed-speed approximation for the real time Railway Traffic Management Problem
Paola Pellegrini, Pierre Hosteins and Joaquin Rodriguez

We assess the validity of the fixed-speed approximation for train speed dynamics in the real time Railway Traffic Management Problem. This is done through a statistical analysis on a number of perturbed scenarios on different railway infrastructures, for different objective functions commonly used in the literature. For each scenario, we analyze the ranking of the generated solutions both in the fixed-speed approximation, obtained by solving the optimization model, and with the variable-speed dynamics, obtained through micro simulation with the OpenTrack software. Our results indicate that some objective functions are somewhat reliable when used in conjunction with the fixed-speed approximation, while others require more detailed studies.

SESSION 7B: 16:10-17:30 ROBUSTNESS 1
Dynamic and robust timetable rescheduling for uncertain railway disruptions
Yongqiu Zhu and Rob M.P. Goverde

Unexpected disruptions occur frequently in railway systems, during which many train services cannot run as scheduled. This paper deals with timetable rescheduling during such disruptions, particularly in the case where all tracks between two stations are blocked for a few hours. In practice, the disruption length is uncertain, and a disruption may become shorter or longer than predicted. Thus, it is necessary to take the uncertainty of the disruption duration into account. This paper formulates the robust timetable rescheduling as a rolling horizon two-stage stochastic programming problem in deterministic equivalent form. The random disruption
duration is assumed to have a finite number of possible realizations, called scenarios, with given probabilities. Every time a prediction about the range of the disruption end time is updated, new scenarios are defined, and the model computes the optimal rescheduling solution for an extended control horizon, which is robust to all these scenarios. Based on the model, uncertain disruptions can be handled with robust solutions in a dynamic environment. The stochastic method was tested on a part of the Dutch railways, and compared to a deterministic rolling-horizon method. The results showed that compared to the deterministic method, the stochastic method is more likely to generate better rescheduling solutions for uncertain disruptions by less train cancellations and/or delays, while the solution robustness can be affected by the predicted range regarding the disruption end time.

Implementation of new timetable rules for increased robustness – case study from the Swedish Southern mainline

Emma Solinen

Due to high demand and high capacity consumption, railway timetables often become sensitive for disturbances and there is little time in the timetables for delay recovery. To maintain a high quality in railway traffic it is important that the timetables are robust and there is a need for strategies and rules for how to make them robust without consuming too much capacity. In this paper we present how timetable rules can be implemented manually to create more robust timetables. The rules are separated into two categories, rules to make the timetable feasible and rules to increase the delay resistance and recovery. The implementation is illustrated in a real-world case from when the timetable for the Swedish Southern mainline was created for 2019. In the paper we describe how new rules can be applied manually and discuss advantages and disadvantages by using this approach. We also describe how the rules effect the trains, their timetable slots and runtimes. The results from this study show some of the difficulties when moving from theory to practice and what can be done with limited resources in reality. It gives insights to the practical approach of train timetabling problem which can be used to improve optimization models.

Impact of perturbations calibration in simulation: the case of robustness evaluation at station

Marie Milliet de Faverges, Christophe Picouleau, Giorgio Russolillo, Boubekeur Merabet and Bertrand Houzel

This paper deals with robustness evaluation at station, and in particular for the train platforming problem (TPP). This problem consists in a platform and route assignment in station for each scheduled train. A classical robustness evaluation is simulation: simulated delays are injected on arriving and departing trains then propagated, and results are averaged on a large number of trials. A robust solution of the TPP aims to limit the average amount of secondary delays. However, a simulation framework at station is difficult to calibrate: it requires a realistic delays generator and an accurate operating rules modeling.

This paper proposes an original simulation framework using classical statistical learning algorithms and calibration assessment methods to model simulation inputs. This methodology is applied on delay data to simulate delay propagation at station. It highlights the importance of delay calibration by showing that even slight miscalibration of inputs can lead to strong deviations in propagation results.
Robust Capacitated Train Rescheduling with Passenger Reassignment under Stochastic Disruption Durations
Xin Hong, Lingyun Meng, Francesco Corman, Andrea D’ariano, Lucas P. Veeleturf and Sihui Long

Railway operation companies provide a more efficient and sustainable service for passengers, so that they can have a stronger competitiveness in the multimodal transportation market. However, in daily railway operation, inevitably unplanned events occur several times per year such as rolling stock break-down, which may influence train running time, as well as arrival and departure time. Under severe disruptions, stop patterns of trains may be changed, even cancelling or inserting certain trains may be taken by dispatchers. Train rescheduling will be quite different and challenging in a railway system with ticket booking mechanism compared with non-reserved mechanism. This paper develops an mixed-integer programing model for the problem of train rescheduling with passenger reassignment on a railway network with ticket booking mechanism under severe disruptions. Passenger reassignment will be taken into consideration to ensure that as many as passengers effected by disruptions may arrive at their destinations as early as possible. The function objective is to maximize transported passengers of cancelled trains, and minimize total delay time of trains at their destination stations, with consideration of planning extra stops for unaffected trains to transport more passengers effected to their planned destinations, seat capacity limitation and uncertainty of disruptions. A constraint will be set to ensure that the same number of passengers are assigned to the same following train(s) under different random disruption scenarios, which imposes the robustness of dispatching. There will be several numerical experiments based on “Beijing-Shanghai” High Speed Railway Line to demonstrate the validity and efficiency of our model.

SESSION 7C: 16:10-17:30 FREIGHT TRAFFIC PLANNING 2
Optimization of Shunting Operation Plan in Electric Multiple Units Depot
Jintang Shi and Haodong Li

The Chinese high-speed rail network has a fast-growing number of electric multiple units (EMUs) in service and is facing increasing pressure of maintaining all EMUs on-time. The capacity at an EMUs depot is relevant to its track utilization rate, which can be improved by a better shunting operation plan. An EMUs depot typically consists of a maintenance yard, washing yard and temporary storage yard. Each track in those yard has two sections, and can be occupied by a long EMU or two separate short EMUs. The two yard types, stub-end and through, further add complexity to the shunting operation problem. Compared to the previous researches, the shunting operation plan studied in this paper takes the yard types and the section assignment into account simultaneously. An optimization model was established aims to minimize the total delay time of EMU in running shed during the plan horizon. The constraints include the numbers of operation tracks and EMUs, operation sequence and the dwell time of operation tracks, etc. The original problem is transformed into a typical job shop scheduling problem with additional space and time constraints. Then a hybrid heuristic algorithm based on Tube Search is designed to solve the model. Finally, by taking a real-world EMU depot as an example, the numerical results show that the proposed solution method can yield an assignment plan with the optimal track utilization in a small amount of computational time and can be implemented in a computer-aided planning system easily.
Improving Freight Operations Using an Integrated Communication Platform

Mahnam Saeednia

Intermodal transportation systems play an important role in fulfilling the growing market needs for freight transportation. Integrity of operations in such systems can be obtained by real-time, and just in-time communication among the involved actors. In In2Rail and X2Rail2 European projects, an integrated communication platform (the integration layer) is developed as a communication medium between railway services, applications, and external systems. This paper introduces the integration layer and shows how this platform can be deployed to enhance the operations of intermodal freight transportation, with a special focus on the management of dynamic demand.

Influence of Mainline Schedule Flexibility and Volume Variability on Railway Classification Yard Performance

C. Tyler Dick and Nao Nishio

Single-railcar shipments of freight that move in multiple freight trains and are sorted at several classification (marshalling) yards during their trip from origin to destination remain an important source of traffic and revenue for North American freight railways. The train plan for a carload freight railway network determines how railcars are sorted into blocks by common destination and transported on trains between yards. To deliver competitive service to freight shippers, practitioners must devise an optimal plan that balances mainline and yard efficiencies while dealing with variation in both train arrival times and inbound traffic volumes. Despite the important role of both mainlines and yard facilities in freight rail transportation performance, little attention is devoted to investigations of classification yard performance, and there are few yard capacity models and tools. To address this railway industry need, the research in this paper seeks to investigate the influence of inbound traffic volume variation and schedule flexibility on classification yard performance and capacity. A series of simulation experiments quantify the interaction between arrival time and volume variability as measured by different yard performance metrics. The simulations are conducted with a discrete-event simulation model developed specifically for analysis of hump classification yards. Preliminary results suggest that increasing schedule flexibility causes classification yard performance to decline. Increasing volume variability appears to have a less pronounced effect. The results of the research will allow railroads to make more informed business decisions regarding train operating plans and make more efficient and economical use of existing yard capacity.

Simulating Railcar Transit Times Under Different Carload Freight Railway Operating Strategies

Tzu-Yu Chang, Darkhan Mussanov and C. Tyler Dick

Single-railcar shipments of freight that move in multiple freight trains and are sorted at several classification (marshalling) yards during their trip from origin to destination remain an important source of traffic and revenue for North American freight railways. Much of this freight moves in trains that depart yards when a certain number of railcars are ready to be moved, and not according to a pre-planned timetable. Recent North American industry trends have seen a move away from these flexible operations to more structured operations where trains depart yards at specific times according to a train plan. This research investigates how operating strategies at classification yards and schedule flexibility of mainline trains combine
to affect the average railcar transit time from origin to destination across a representative rail network. Experiments comparing different yard operating strategies under varying degrees of schedule flexibility were conducted using SIGMA simulation software. Simulation results suggest that railcar transit time increases as the level of schedule flexibility increases under all three of the studied operating strategies. Several factors, including the timing and distribution of railcars on inbound trains arriving at the yard, and frequency of outbound train departures, influence the sensitivity of transit time to schedule flexibility under different operating strategies. There is no universal best strategy to minimize railcar transit times; different traffic scenarios require different operating solutions. This research may help railway practitioners develop more effective operating strategies to improve carload freight operations and performance, and influence decisions on yard operations and train assembly planning.

SESSION 7D: 16:10-17:30 STRATEGIC PLANNING
Sustainability of Railway Passenger Services – A Review of Aspects, Issues, Contributions and Challenges of Life Cycle Emissions
Marko Kapetanović, Niels van Oort, Alfredo Núñez and Rob M.P. Goverde

This paper presents a review of research and models regarding sustainability of railway passenger services. In order to take into account all relevant aspects in terms of environmental impacts of a railway passenger service, a holistic system perspective is required, that includes a whole life cycle assessment. A life cycle approach is important since comparison of for instance only the exhaust emissions of an electric vehicle with a petrol vehicle is misleading, due to neglecting the emissions of for instance electrical energy production process. Thus, all stages in energy carrier, vehicle and infrastructure life cycles are to be considered. Existing models are analyzed, as well as possible developments, focusing on diesel and electrical traction as the most common traction options in use, and on GHG emissions, especially on CO2, which takes the greatest part in all emissions. Issues and challenges in improving the environmental impact of railway passenger services are addressed. Additionally, several areas are indicated where environmental aspects could be included in future assessment models. The main challenge is answering how the existing partial assessments can be brought together and, together with filling the identified gaps, allow to conduct a comprehensive LCA which will produce real-world emissions estimations. Results of this paper will be used as an input in developing a framework for quantifying and improving overall environmental impacts of a railway passenger service.

Seat Inventory Control Problem in China High-speed Railway: A Simulation-based Heuristic Method
Wuyang Yuan, Lei Nie, Xin Wu and Yu Ke

Seat inventory control is a railway revenue management method that aims to maximize profits by determining the availability of products via a prepared rule/strategy (referred to as the seat inventory control policy). In past decades, the most famous type of seat inventory control policy was partitioned booking limit control (PBLC), which was extensively applied by railway companies but observed to be inefficient for stochastic demand. In recent years, China Railway Corporation attempted to overcome this deficiency by applying a new type of seat inventory control policy, denoted “seat-based control”. Seat-based control provides a more flexible way to manage resources but has encountered difficulty in setting the initialization parameters. This
study focuses on the parameter setting problem for seat-based control considering i) the randomness of customer arrival, ii) the customer choice behavior and iii) the specifics of China Railway Corporation. A Markovian decision process (MDP) model is built, and a genetic algorithm method with a special structure is designed. The performance of the seat-based control is tested in two experiments with two other benchmarks. Finally, we apply our method to practical data of the Nanning-Guangzhou high-speed railway line.

**Improving the Trade-Offs Between Network Availability and Accessibility**

*John Armstrong, John Preston and Tolga Bektas*

Passenger and freight traffic growth on Britain’s railways has led to increased needs for maintenance, renewal and enhancement of the national railway network, and reduced opportunities for access to the network to conduct these engineering activities without disrupting operations. As a result, the costs of compensation to operators for service disruption and revenue loss have been increasing in line with traffic levels. There tends to be a trade-off between the cost efficiency of engineering activities and the compensation costs for the operational disruption caused, since longer track possessions are typically more efficient, but also more disruptive, reducing network availability for operations. There is thus a need to reduce and, ideally, minimise the total costs of engineering activities and compensation for the disruption caused. The current possession planning process does not actively aim to minimise service disruption and compensation costs, much less the combined engineering and compensation costs. A further, detailed review of the current possession planning process, including data availability and needs, is being undertaken, and, together with the results of recent research, will be applied to (i) amend the current possession planning process to reduce its disruptive impact and compensation costs, thus increasing network availability for operations, and (ii) to identify data requirements to enable the assessment of duration, engineering costs and timetable impacts/compensation costs associated with alternative possession strategies, and apply these in combination with scheduling techniques to reduce and, ideally, minimise combined engineering and compensation costs.

**Tuesday, June 18**

**Session 9A: 09:00-10:20 Traffic Management 3**

*Pre-planned Disruption Management in Commuter Railway Transport: Algorithms for (partial) Automation of passenger-oriented Design and Evaluation*  
*Anna-Katharina Brauner and Andreas Oetting*

Disruption management applying disruption programs helps to amend disruption operations. Pre-planned train dispatching instructions for a specific disruption situation facilitate the work of the dispatchers. Those instructions are mostly manually designed and often focus solely on the train runs. The proposed approach aims to improve the quality of disruption programs concerning operations and especially concerning the reduced passenger mobility. For this purpose, the algorithms to be presented evaluate the operating concept on its functionality and reachability in a solely train operations focused way. A stable and fast transitioning disruption program is already enhancing the passenger mobility in a disruption, but it is not enough to call it passenger-friendly. For this purpose, the algorithms design a transportation
concept including passenger guidance measures and comprise a final evaluation of the disruption program in a passenger-oriented way.

Analysis of Timetable Rescheduling Policy for Large-scale Train Service Disruptions
Rieko Otsuka, Masao Yamashiro, Itaru Ootsuchibashi and Sei Sakairi

When a train disruption happens, hundreds of train dispatchers need to quickly make a rescheduling timetable plan for train service recovery by taking account of various constraints. Complexity of rescheduled timetable for a large-scale train service disruption changes significantly depending on rescheduling policy like turn around operation because it requires additional train arrangements. Then, dispatchers should decide rescheduling policy first of all to make their timetable rescheduling plan. These decision making are quite important and rescheduling operations depends on dispatcher’s individual skills currently. One of the most important issues is rescheduling techniques are not inherited among dispatchers effectively. Therefore we propose a new data-driven approach to support dispatcher’s decision based on historical train timetable data. We analyzed the past timetable data of railway service line in the Tokyo Metropolitan area and automatically extracted primary rescheduling components such as train cancellation. We have verified accuracy of our method regarding turn around operation by comparing with dispatcher’s manual report. The result indicates estimation accuracy was more than 90%. In addition, we have developed the prototype system which suggests rescheduling policy to dispatchers.

Real-time Train Platforming and Routing at Busy Complex High-speed Railway Stations
Jia Ning, Qiyuan Peng and Gongyuan Lu

This paper focuses on the real-time train platforming and routing problem at a busy complex high-speed railway station in a disrupted situation caused by malfunctioning railway infrastructure or train primary delay. When the disruption occurs, dispatchers need to reassign trains to the conflict-free platform and route, even reschedule the arrival and departure times. To this end, we develop a mixed-integer linear programming formulation that determines platforming and routing decision simultaneously, while allowing trains to be rescheduled when the initial schedule imposes irreconcilable conflicts. The objective of our model is to minimize the overall deviation from the planned schedule and the original platforming plans. To improve the solving efficiency, an iterative algorithm is proposed to compute near-optimal solutions in a short computation time, which is based on the decomposition of the overall problem into two sub-problems: (i) platform and route assignment with fixed arrival and departure times, (ii) partial conflict trains rescheduling. The connecting information between two sub-problems concerns the index of conflict trains and the new train timetable. To solve sub-problem (i) efficiently, we develop a branch and bound algorithm which includes implicational rules enabling to speed up the computation and still can acquire optimal solutions. Since the model of sub-problem (ii) is the same as the model of original problem but has a relative small scale, it can be efficiently solved by CPLEX solver. A real-world instance with operation data of Zhengzhou East high-speed railway station, is implemented to demonstrate the performance and effectiveness of the proposed algorithm.

A conflict prevention strategy for large and complex networks in real-time railway traffic management
Train timetables are built such that trains can drive without any delay. However, in real-time, unexpected events such as overcrowded platforms or small mechanical defects can cause conflicts, i.e., two trains requiring the same part of the infrastructure at the same time. Currently, such conflicts are typically resolved by experienced dispatchers. However, it is impossible for them to fully anticipate the impact of their actions on the entire network. Conflict detection and prevention tools embedded in a Traffic Management System can help them in making informed decisions. Though some advanced train movement prediction and conflict detection has been developed in the last years, there still exists a need for conflict prevention strategies capable of delivering conflict resolutions on large and complex networks based on retiming, reordering and rerouting some of the trains in real-time.

Our previous work introduced such a conflict prevention strategy that, based on offline calculations, determined which part of the network should be regarded when deciding on a conflict resolution. This work is significantly extended here by considering several new parameters for the Dynamic Impact Zone heuristic. This paper compares results on different sizes of networks, and tackles the challenges for applying the strategy on even larger networks.

SESSION 9B: 09:00-10:20 SYSTEM DESIGN, VALIDATION AND EVALUATION

Online calibration of train motion models: towards the era of bespoke control solutions
Valerio De Martinis and Francesco Corman

The onboard collection of data related to train operation enables a better calibration of the current train motion models, which are fundamental for the elaboration of optimized train control solutions. Here, the possibility to implement an online calibration of train motion models, i.e. to set the model’s parameters for the single train on the go, is explored. For this purpose, a comparison of different calibration models is proposed. Then, the performances of the models are evaluated according to the requirements for online elaborations. In the end, possible further requirements and limitations on the use are discussed.

Centralizing and migrating operational infrastructure databases
Alexander Kuckelberg and Bianca Multykin

Since years and decades, IT systems are used to plan, to monitor and to control train operations and railway traffic on network regions. Especially in technically advanced railway networks, the usage of computer based systems for dispatching and controlling traffic started quite early, e.g. large innovation programs in the 90s like Bahn2000 in Switzerland or BZ2000 in Germany and more. One component of these systems is a database component managing infrastructure data and topology information.

Infrastructure databases usually are dedicated to regions of responsibilities, e.g. “Niederlassung” or “Regionalbereich”, managing infrastructure data for the corresponding region and bordering areas, e.g. lines and tracks from the region leading to surrounding regions. In this way, several, similar databases exists with partially overlapping data. With new IT systems, larger systems covering more regions are possible. Following an evolving (instead of an revolution) approach processes to merge and consolidate existing data and systems are required.

This talk presents an approach for migrating legacy databases and data structures from
different, overlapping regions and for performing consistency checks with respect to topology, connectivity and infrastructure content and semantical matching of regional data. The talk will present algorithms, heuristics and processes to merge and analyse consistency of consolidated infrastructure databases as developed and evaluated within real-world projects.

**Sound evaluation of simulation results**
Thorsten Büker, Matthias Becker, Eike Hennig and Felix Kogel

Simulation is one of the powerful means within the toolset of railway operations research. In contrast to pure timetabling and to queuing theory, it supports a precise representation of interdependencies. There is long-lasting series of research and only some exemplary publication can be listed. Some microscopic simulation tools provide an explicit conflict detection and solution a synchronous and/or asynchronous manner. Recently optimisation components are applied within conflict solution, too. While either the simulation algorithm or the simulation evaluation is addressed within a variety of publications, the execution of studies relies on an important interim step: aggregation, validation and interpretation of simulation (raw) data. Barely no literature can be found. This fundamental task is subject of this paper. A -- mostly -- standardised principle how to eliminate modelling errors and ensure comparability of results is introduced. The principle is based on experience gathered in various consultancy activities.

**A Collection of Aspects Why Optimization Projects for Railway Companies Could Risk Not to Succeed - A Multi-Perspective Approach**
Christian Liebchen, Hanno Schülldorf and N.N.

You might be aware of the following gap: There are by far more publications on promising projects on how mathematical optimization could improve the performance of railway companies, than true success stories in the sense that operations research methods really entered the practice of railways.

In this paper, we shed a bit of light on those projects, which finally did not enter the practice of railways. We do so by conducting a survey in which we ask both, railway practitioners who served as ordering party, and optimization experts who served as R&D solution provider. By summarizing the most frequent replies to our question about the key factors why in the past mathematical optimization methods did not enter the practice of railways, we offer this knowledge base to future project managers. Acting accordingly with respect to definition of project goals, project design, and project management, hopefully lets them come up with even more true success stories of operations research methods in the practice of railways.

**SESSION 9C: 09:00-10:20 DELAY ANALYSIS AND PREDICTION 2**

**Data reconciliation of freight rail dispatch data**
William Barbour, Shankara Kuppa and Daniel Work

In order to enable widespread use of data driven analysis and machine learning methods for rail operations problems, large volumes of operational data are needed. This data has the potential to contain erroneous or missing values, especially given its size and dimensionality. In this work a data reconciliation problem for rail dispatch data is proposed to identify and correct errors, as well as to impute missing data. The data reconciliation problem finds the least-
perturbed modification of the historical data that satisfies operational constraints, such as feasibility of meet and overtake events, safety headway, siding allocation, and running time. It also imputes missing values with estimates that satisfy all operational constraints. The data reconciliation method is applied to a large historical dataset from freight rail territory in Tennessee, United States, containing over 3,000 train records over six months. The method identifies and corrects errors in the historical data, and is able to impute data on a synthetically decimated version of the historical data. The quality of the imputed data from data reconciliation is compared to imputed data using naive interpolation. The results show that data reconciliation reduces timing error of imputed points by up to 15% and increases the number of meet and overtake events estimated at the correct historical location from less than 40% to approximately 95%. These findings indicate that the data reconciliation method is a useful preprocessing step for analysis and modeling of railroad operations that are based on real-world physical dispatching data.

Predictive Model of Train Delays in a Railway System
Weiwei Mou, Zhaolan Cheng and Chao Wen

Delay prediction is an important issue associated with train timetabling and dispatching. Based on real-world operation records, accurate estimation of delays is of immense significance in train operation and decisions of dispatchers. In the study, we established a model that illustrates the interaction between train actual delays and the factors affecting the same via train operation records from a Dutch railway system. Based on the main factors that affect train delay and the time series trend, we identified the independent and dependent variables. A long short-term memory (LSTM) prediction model in which the actual delay time corresponded to the dependent variable was established via Python. Finally, the prediction accuracy of the random forest model and artificial neural network model was compared. The results indicated that the LSTM model outperformed other models.

A Hybrid Forewarning Algorithm for Train Operation under Adverse Weather Conditions
Jun Zhang, Yuling Ye and Yunfei Zhou

This paper presents a combined method of fuzzy theory and rough sets theory for the early warning of high-speed railway (HSR) under adverse weather conditions. Based on the monitoring data of meteorological indicators along the railway, a fuzzy c-means (FCM) clustering is first applied in order to figure out the fuzzy distribution of sample data and to fit the corresponding membership function of every indicator. According to the clustering results, every original sample is transformed into its cluster level as string data for the subsequent application of rough sets theory. Then a series of effective rough rules between conditional indicators and the decision indicator is extracted after attribute reduction by the Rosetta toolkit, where the decision indicator is represented by the train deceleration rate. Since the value of an indicator may correspond to several fuzzy levels, the multiple combinations of different conditional indicators will activate multiple rough rules. In order to forecast a clear value of the decision indicator, a centroid-based Max-Min compound arithmetic is applied to clarify relevant rules and determine the warning level. Using the designed algorithm, a case analysis of an HSR line section is conducted to verify the feasibility of the combined method, all meteorological data and operation records are provided by the Shanghai Railway Bureau in
China. The results prove that the hybrid algorithm can be applied in the real-time forewarning of HSR train operation, with a global accuracy over 86%.

A STUDY ON TRAIN TRAVEL TIME SIMULATION FOCUSED ON DETAILED DWELL TIME STRUCTURE AND ON-SITE INSPECTIONS
Shigeaki Adachi, Masahito Koresawa, Giancarlos Troncoso Parady, Kiyoshi Takami and Noboru Harata

To reduce passenger congestion during morning rush hour, railway companies in the Tokyo metropolitan area have increased the number of trains. On the other hand, once a train exceeds a dwell time due to sudden events such as passengers rushing onto a train, passengers agglomerating in specific cars and doors, objects getting caught in doors etc., delays propagate to subsequent trains quickly. To evaluate daily train transport stability and countermeasures against train delays, a train travel time simulation model is needed. However, it has been difficult so far to replicate the occurrence of sudden events and the fluctuations in passenger demand. In this paper, we use detailed data based on dwell time structure and on-site inspections to construct a train travel time simulator. In addition, we evaluate several case-studies of timetable adjustments and passenger demand variations.

SESSION 9D: 09:00-10:20 MOVING BLOCK
Enhancement of blocking-time theory to represent future interlocking architectures
Thorsten Büker, Thomas Graffagnino, Eike Hennig and Alexander Kuckelberg

Recently, railway-infrastructure managers and suppliers have launched major programs with the aim to revise – or even reinvent – the overall interlocking architectures plus adjacent systems and operational principles. Representatives of such initiatives are "SmartRail 4.0" and “Digitale Schiene Deutschland”. Those programs are backed-up by a set of motivations, namely: Existing command and control technology is overaged or becomes outdated, skills to maintain technology get lost due to demographic aging, applied technology is expensive and does not allow any further capacity gain.

Since capacity improvement is a core target of all programs, there is a severe need to express the capacity impact of the related system architecture. Such quantifications serve the broad portfolio from political decision processes to detailed requirement specifications.

This article describes necessary extensions of the blocking-time model to meet the requirements of future interlocking architectures in detail. It contributes to extent the standardised blocking-time model in such a manner, that its applicability is ensured in different setups. Besides providing and extending the theoretic background, the article provides examples of practical computations and applications. They cover sensitivity analysis to elaborate the decisive impact parameters on headway times as well as timetabling-studies based on a future technology setup.

Train Flow Shockwaves on Freight Railways Operating Under Moving Block Control Systems
Adrian Diaz de Rivera, C. Tyler Dick and Leonel E. Evans
To accommodate increased demand for safe, efficient, and reliable freight and passenger rail transportation, North American railways are investigating implementing advanced communications-based train control (CBTC) systems with moving blocks to increase capacity of existing track infrastructure and leverage previous investments in Positive Train Control (PTC) technology. Under moving blocks, trains can operate at short headways based on individual train braking characteristics and track occupancy. Therefore, railway traffic flow, traditionally governed by fixed block signals, may begin to resemble highway traffic flow consisting of a continuous stream of vehicles interacting directly with each other. This research investigates if operations of freight trains around capacity bottlenecks caused by vertical grades or speed restrictions and controlled by moving blocks or fixed block wayside signal systems create shockwaves similar to those found in highway traffic streams. A macroscopic model is developed to produce density-flow curves describing operations of saturated, unidirectional, homogenous rail traffic around various combinations of grades and track speeds. Industry-standard railway traffic simulation software is used to validate the methodology. Model inputs and simulation headways are based on braking distances calculated for a typical North American bulk unit freight train. Results indicate that shockwave theory can predict the behaviour of rail traffic under fixed block and moving block control systems around stationary capacity bottlenecks caused by geography or civil speed restrictions. This knowledge can inform railway practitioner decisions on investment in advanced CBTC with moving blocks, future railway capital plans, and operating plans for new and existing lines with stationary bottlenecks.

Train Operation Simulator under Moving Block and Prediction Control
Taketoshi Kunimatsu, Takahiko Terasawa and Yoko Takeuchi

This research focuses on developing a simulation system which can estimate train traffic or passenger flow under new train control systems. The goal of our research is to evaluate effects of installing intelligent signalling system or train control system, such as moving block or prediction control.
In our previous work, we had developed “Train operation/passenger behaviour simulator,” which estimates passengers’ train paths, train congestion, and train delay under a certain timetable. In that simulator, train delay is predicted by estimating train operation curves of each train between stations. However, train operation curves could be calculated under fixed block signalling systems only. So, we cannot estimate effects of new train control systems, like moving block or prediction control.
In this research, we devised the fast estimation method for train operation curves under moving block. By that method, train operation curves can be calculated almost the same calculation time as that under fixed block. We also devised train control algorithm based on prediction control theory under moving block to minimize headway between successive trains. We then implemented those methods to the simulator, and evaluated effects of installing moving block signalling system and prediction control in an actual commuter line in Japan.

A multi-state train-following model for the analysis of Virtual Coupling railway operations
Egidio Quaglietta, Meng Wang and Rob M.P. Goverde

The increasing need for capacity has led the railway industry to explore next generation signalling concepts such as Virtual Coupling which takes moving-block operations further by separating trains by a relative braking distance, like cars on the road. By means of a Vehicle-to-
Vehicle (V2V) communication architecture trains can move in a virtually coupled platoon which can be treated as a single convoy at junctions, to improve capacity. This concept however introduces the need for additional safety constraints, especially at diverging junctions, which could make actual capacity improvements insufficient to justify investments. Hence, there is a need to understand capacity performances of Virtual Coupling and potential gains over state-of-practice signalling systems. This paper addresses this need by developing an innovative train-following model that captures operational states and corresponding transitions of trains running under Virtual Coupling. A comparative capacity analysis has been conducted for a portion of the South West Main Line in the UK. Promising results have been obtained, showing that the biggest capacity gains returned by Virtual Coupling relate to operational scenarios normally found in practice with trains having service stops and using different routes.

SESSION 10A: 10:50-12:10 TRAFFIC MANAGEMENT 4

Train Rescheduling Incorporating Coupling Strategy in High-speed Railway under Complete Segment Blockage

Dian Wang, Jun Zhao, Liuyang Lu and Qiyuan Peng

This paper investigates the real-time train rescheduling problem in a high-speed railway line under a complete segment blockage by exploring the effectiveness of incorporating train coupling strategy on the train timetable rescheduling. The problem lies on determining the actual arrival and departure time as well as the platform track assignment of trains at stations after a complete segment blockage caused by disruptions, where reasonable trains satisfying strict rules could be coupled with others to avoid being cancelled. A novel mixed integer linear programming model is formulated to minimize the total deviation of trains' arrival and departure time to that in the planned timetable. In the model, both the acceleration and deceleration time of trains when departing from and arriving at stations are explicitly considered, while the platform track of trains at passed stations is jointly optimized. A rolling horizon algorithm is designed to effectively solve large-scale problem instances since the rescheduling of timetables is usually determined in stages in practice. Test instances constructed based on the Wuhan-Guangzhou High-Speed Railway in China are utilized to test the effectiveness and efficiency of the proposed approaches. Computational results demonstrate that the train coupling strategy is likely to reduce the total deviation and to relief the propagation of delays. Meanwhile, the rolling horizon algorithm can provide practically acceptable rescheduled timetables quickly. Thus, the train coupling strategy is promising in the field of train timetable rescheduling to cope with large-scale disruptions.

Proactive Dispatching of Railway Operation

Markus Tideman, Ullrich Martin and Weiting Zhao

Railway networks are often operated close to their full capacity due to limited infrastructure expansion and increasing traffic demand. Hence, basic timetables are fairly vulnerable to random operational disturbances. In consequence of this, the service level for passengers decreases through a combination of delay propagation and delay accumulation. To solve this problem, a possibility widely used in research is to add extensive recovery and buffer times. Nevertheless, the resulting robust basic timetables would lead to a deterioration of the operating capacity, especially in congested areas. Another approach to reduce the impact of operational disturbances on railway operation is to use conventional dispatching algorithms.
Unfortunately, most of them ignore further potential disturbances during the dispatching process, which is why the generated dispatching solution might even worsen train’s punctuality.

In this context, at the Institute of Railway and Transportation Engineering (IEV) at the University of Stuttgart a proactive dispatching algorithm has been developed, that generates dispatching solutions under the consideration of random disturbances in dynamic circumstances. The algorithm is divided into two main processes. First, the block sections are classified depending on their operational risk index by simulating numerous timetables with random disturbances generated in a Monte Carlo scheme and the related negative impacts in the studied railway network are calculated. Second, near-optimal dispatching solutions are automatically generated based on Tabu Search algorithm. This is achieved within a rolling time horizon framework, taking risk-oriented random disturbances in each block section into account.

Coordinated railway traffic rescheduling with the Resource Conflict Graph model
Ambra Toletti, Marco Laumanns and Ulrich Weidmann

The train rescheduling problem is quite a popular topic in the railway research community. Many approaches are available to reschedule traffic in a network partition but very few works address the coordination of these partitions. In railway systems with very dense traffic, e.g. the Swiss one, it is not always possible to partition the network such that the rescheduling algorithms can work on completely independent regions. This paper proposes a coordination approach for adjacent local rescheduling algorithms. These algorithms are based on the Resource Conflict Graph model, which enables the representation of the interlocking system at a very fine granularity. Simulations on data from the Swiss Federal Railways show the validity of this approach in improving the consistency of decisions at the common boundaries of adjacent local rescheduling algorithms.

A Heuristic Algorithm for Re-Optimization of Train Platforming in Case of Train Delays
Yongxiang Zhang, Qingwei Zhong, Chao Wen, Wenxin Li and Qiyuan Peng

Train platforming is critical for ensuring safety and efficiency of train operations within the stations, especially when train delays occur. This paper studies the problem of re-optimization of train platforming, where the train station is modeled using discretization of the platform track time-space resources. To solve the re-optimization problem, we propose a binary integer programming model which minimizes the weighted sum of total train delays as well as platform track utilization costs, subject to constraints defined by operational requirements. Moreover, we design an efficient heuristic algorithm to solve the model with a good precision. A real-world case is taken as an example to show the effectiveness of the proposed model and algorithm. The results show that the model established in this paper can describe re-optimization of train platforming accurately and can be solved quickly by the proposed heuristic algorithm. In addition, the model and algorithm developed in this paper can provide an effective computer-aided decision-making tool for the train dispatchers in case of train delays.

SESSION 10B: 10:50-12:10 CAPACITY ANALYSIS 3
A Graph Application for Design and Capacity Analysis of Railway Junctions
Predrag Jovanovic, Norbert Pavlovic, Ivan Belosevic and Sanjin Milinkovic
In this paper, an analytical model for strategic decision-making is developed, which makes it possible to compare and select the best solution of several railway junction designs according to theoretical infrastructure capacity, completely independent of timetable. The model achieves triple effects because, besides the above, it enables the selection of the most favorable sequence of train traffic through the junction, as well as determining the theoretical junction capacity. Model uses well-known combinatorics problems to determine the minimum infrastructure occupancy time. Testing has shown the simplicity of model implementation, as well as a satisfactory level of accuracy.

**Railway Infrastructure Capacity Utilization Description through Data Integration in Blocking Time Theory**

*Qinglun Zhong, Shaoquan Ni, Chang'An Xu and Shengdong Li*

We propose a method to describe capacity utilization for railway infrastructure that applies blocking time theory to managing train runs. Different from traditional capacity evaluation, infrastructure capacity utilization description shows detailed information on infrastructure utilization hidden in timetabling data instead of sheer number of trains that can be operated, or capacity consumed. Using a function system defined upon necessary operational inputs for timetabling in blocking time theory, we can obtain the feasibility condition for operating consecutive trains. Thus, the method to identify critical block section can be deduced from the feasibility condition. Structural indication determines the capacity utilization of consecutive train paths, which can be further integrated into a bi-directional graph to model infrastructure capacity utilization description followed by infrastructure time allocation. Consumed capacity of railway infrastructure by operating train runs can be formulated. Besides, a general procedure is proposed to analyse the sensitivity of consumed capacity to operational inputs. An experimental case study is conducted to demonstrate the application of this method in analysing the impact of speed and recovery time.

**Quantifying the effects of variability on the capacity of rail corridors**

*Norman Weik and Nils Nießen*

Traffic variability is well known to have a substantial effect on railway capacity. Varying train running and stopping times entail larger train separations and yield non-usable time slots in train timetables and operations. In the present paper we aim to assess the effects of variability on the capacity of railway corridors in long term planning of rail traffic. Our main focus are metro transit systems in urban areas, where the effects of fluctuations of running and stopping times are particularly pronounced due to dense operations. The investigation comprises uncertainty of train stopping and running times as well as of the traffic concept itself, such as variations of headways and line frequencies.

On the system level, inhomogeneity tends to propagate in the network, yielding non-usable capacity, which is why we propose a stochastic modeling of rail corridors. Our model is motivated by finite capacity transfer lines, which have been studied in the context of manufacturing systems. The corridor is viewed as a sequence of heavily correlated service stations representing line segments and stations, for which effective throughput, distributions of train running times and service quality are calculated. The performance of the model is tested in a case study for the central link of the mass transit system in Cologne. In addition, an
Computing Base Train Equivalents for Delay-Based Capacity Analysis with Multiple Types of Trains
Tzu-Ya Lin, Ying-Chun Lin and Yung-Cheng Lai

Different types of trains may have substantially dissimilar characteristics, resulting in various capacity impacts. The concept of base train equivalent (BTE) was proposed to standardize different train types into a universal unit, namely, base train unit (BTU). However, the previously developed delay-based model suffers from consistency issue, and its application is limited to only two train types. Thus, this study proposes a new concept of delay-based BTE computation and corresponding BTE models. The dynamic BTE model considers volume and heterogeneity and aims to reflect fully the actual capacity impact of non-base trains. The fixed BTE model identifies the most appropriate BTE value at a particular traffic heterogeneity. Results from the case studies demonstrate that the proposed method can address scenarios with all types of traffic mixes and multiple train types. The unit of delay-based rail capacity can be converted into a standard unit using the proposed models. The effect of an additional train can be easily assessed, and the capacity measurements from different lines or systems can be compared and evaluated.

SESSION 10C: 10:50-12:10 TIMETABLING 3
Passenger-orientated analysis of allocation of railway capacity with help of simulation
Jennifer Warg and Markus Bohlin

Railway capacity analysis usually aims to allocate the existing tracks to the desired traffic. Usually, track occupancy or indicators as delays are used to estimate how the system performs. In this article, we analyse the interaction of commuter and express train services. With help of microscopic simulation with RailSys, characteristics as delays are estimated for the regarded timetable slots and converted into a performance index. Assuming that the number of travellers is known, these individual indices can be converted into an index for the timetable alternative.
A case study is performed on the Swedish Western Main line. Simulation is procured for all services on the line. Based on the results, an index is calculated for the respective timetabling alternatives. In that way, the effect of in-/decreased primary delays and supplements as well as major disturbances is analysed.
The model is shown to be relevant for capacity allocation and can be helpful for the timetabling process when the passenger demand can be estimated. Estimated delays can have larger impact than differences in travel times. The analysis also showed that with the commonly used valuations, socio-economic effects on commuter trains are much lower than for long-distance trains. For further development of the model, an adjustment of these parameters should be considered.

A train timetabling and stop planning optimization model with passenger demand
Weining Hao, Lingyun Meng, Francesco Corman and Sihui Long

Train timetabling plays an important part in train management, not only for passengers, but also for train operators. In a highly dynamic transportation market, train timetabling is an
essential bridge connecting the service supplier with transportation demand. However, in present operations, train scheduling without considering passenger demand can reduce competitive advantages of railway in the multimodal transportation market and will further lead to passenger dissatisfaction. Therefore, it’s important to schedule trains responding to passenger demand in the train planning process. In this paper, we focus on the problem of train timetabling with passenger demand, specifically deciding train stop plan based on different origin-destination passenger demand pairs. Taking the stop indicators as important decision variables, a mixed integer linear programming model is proposed to address this train timetabling and stopping plan integration issue, with minimizing total train travel time and maximizing the number of transported passengers. The weighted-sum method is used to find the Pareto optimal solutions for the proposed bi-objective mathematical model. A set of numerical tests is presented based on Beijing-Jinan high-speed railway line (part of Beijing-Shanghai high-speed railway line) by Cplex optimization solver to validate the model.

A Concurrent Approach to the Periodic Event Scheduling Problem
Ralf Borndörfer, Niels Lindner and Sarah Roth

We introduce a concurrent solver for the periodic event scheduling problem (PESP). It combines mixed integer programming techniques, the modulo network simplex method, satisfiability approaches, and a new heuristic based on maximum cuts. Running these components in parallel speeds up the overall solution process. This enables us to significantly improve the current upper and lower bounds for all benchmark instances of the library PESPlib.

Finding feasible timetable solutions for the Stockholm area
Olov Lindfeldt

MTR (Mass Transit Railway) is contracted by Stockholm Public Transport (SLL) to operate the Stockholm commuter trains. The number of passengers is increasing and traffic is expected to increase by 50% in ten years. This will therefore require further investigations to enable investments in additional infrastructure and rolling stock.

A generic model has been developed in order to screen future timetable situations and find resource efficient timetable alternatives and investments needed to enable the expected traffic increase.

Short turning traffic lines is one way to reach high efficiency for a commuter system. However, the sequence of short turning and full route lines will affect congestion heavily. Consequently different permutations of a termination pattern results in different passenger distributions on the traffic lines. The core idea of the timetabling model is to combine congestion efficient permutations for the four branches into network timetables.

A number of important features of the timetable are influenced by the choice of termination patterns, permutations of these patterns, the time rotation of the entire timetable and the requisite of symmetry. The latter is required in order to enable long distance traffic on shared line sections. Examples of important features are: the termination times, the number of train set needed, the need for additional termination tracks and the recovery and punctuality that can be reached.

A brief description of the commuter rail network, the demand and the prerequisites for the timetable are presented and discussed. Similarly the main ideas of the generic model are outlined. The method is elucidated by an illustration of a future traffic increase by 25%.
SESSION 10D: 10:50-12:10 DRIVER BEHAVIOUR AND SUPPORT

Taking Driver Advisory Systems to the next level
Per Leander and Andreas Törnblom

Description/outline of the development trends beyond current standalone Driver Advisory Systems; C-DAS, Intelligent Cruise Control and use of the technology for ATO.

Understanding the Impact of Driving Styles on Reactionary Subthreshold Delays on a Fixed Block Signalling System
Oliver Bratton and Giorgio Medeossi

Braking curves from on-train data recorders from 2002 and 2018 are compared to identify changes in braking styles in the UK over time. The changes, typically of four seconds for each braking curve from 60mph to 0mph, are then assessed to understand how these small changes affect the operation of fixed block signalling systems.

The contribution of these small delays are then simulated in the "trenissimo" micro simulation tool to better understand how small changes in driving styles can contribute wider system performance through the spread of sub-threshold delay, and thus increase the delay per incident.

User-centered development of a train driving simulator for education and training
Birgitta Thorslund, Tomas Rosberg and Anders Lindström

A user-centered, agile approach was used to develop a high-standard train simulator for applications in train driver education. A user group of train operators and train driver educators was formed to share experience and cut development cost. Joint prioritisation by the user group was used in combination with agile development to iteratively develop new variants of the train simulator, with features tailored to the user group’s needs. The user group has grown from 2 organisations in 2015 to 10 organisations in 2019, each of which now use the train simulator in education and training. They find that this has been beneficial in terms of quality, cost or time. Regarding research, this scheme has resulted in three PhD projects and several other projects on driver behaviour, railway signalling systems and capacity.

Train Trajectory Optimization with Consideration of Human Operator Needs and Parametric Uncertainties
Pengling Wang and Francesco Corman

The purpose of this study is to develop a method for calculating the train trajectory in an uncertain environment in which the values of system parameters are difficult to determine. The method takes into account the human operator needs of avoiding possible hazards and extra workloads. A novel Approximate Dynamic Programming (ADP) method is proposed for optimization the train trajectory in real-time. To demonstrate the effectiveness of the proposed algorithm, we conduct a numerical simulation with real-life infrastructure, train and timetable data. We conduct deterministic optimization, which regards the system as having no uncertainty in its parameters, and then perform stochastic optimization (ADP), which takes the
uncertainty into account in the optimization process, and compare the outcomes. The results successfully verify the effectiveness of our proposed algorithm.

SESSION 12A: 13:50-14:50 TIMETABLING WITH REDUCED CAPACITY

Re-optimizing ICE Rotations after a Tunnel Breakdown near Rastatt
Boris Grimm, Ralf Borndörfer and Thomas Schlechte

Planning rolling stock movements in industrial passenger railway applications is a long-term process based on timetables which are also often valid for long periods of time. For these timetables and rotation plans, i.e., plans of railway vehicle movements are constructed as templates for these periods. During operation the rotation plans are affected by all kinds of unplanned events. An unusual example for that is the collapse of a tunnel ceiling near Rastatt in southern Germany due to construction works related to the renewal of the central station in Stuttgart. As a result the main railway connection between Stuttgart and Frankfurt am Main, located on top of the tunnel, had to be closed from August 12th to October 2nd 2017. This had a major impact on the railway network in southern Germany. Hence, all rotation plans and train schedules for both passenger and cargo traffic had to be revised. In this paper we focus on a case study for this situation and compute new rotation plans via mixed integer programming for the ICE high speed fleet of DB Fernverkehr AG one of the largest passenger railway companies in Europe. In our approach we take care of some side constraints to ensure a smooth continuation of the rotation plans after the disruption has ended.

Timetable rules and strategies for double track maintenance work
Magnus Backman and Emma Solinen

When large maintenance work is done at a double track line, it is often possible to have one of the two tracks open for traffic. The traffic then run with single track operation which heavily affects the capacity and need to be planned in an early stage, before the yearly timetable is finalized. Today, in Sweden, there are some difficulties when planning for maintenance works and how to adapt the reduced capacity in the timetable. Due to an increased demand for capacity and for better punctuality from train operators, there is a need for more well thought-out strategies for how to handle the capacity restriction and for how much robustness is needed in the timetable to preserve a certain quality.

In this paper, we present a study which assess strategies for double track maintenance work leading to single track operations. A simulation study is performed in which three different timetable strategies are tested and evaluated. The aim is to find strategies and timetable rules to better handle capacity reductions at double track lines so that trains can run with high quality even though there are maintenance works at the same time.

In the paper we discuss the advantages and disadvantages with the three strategies and how they affect train slots, runtimes and punctuality. We propose a strategy for how to best consider single track operations, depending on the length of the single track section, speed restriction and traffic pattern, including hands-on timetable rules.

Optimal Timetables in case of Temporarily Unavailable Tracks
Sander Van Aken, Sofie Van Thielen and Pieter Vansteenwegen
Train passengers expect a high level of service under all circumstances, while disruptions occur on a daily basis. In some countries, dispatchers have predefined emergency plans at hand. These plans’ flexibility and applicability are questionable as disruptions may be unique in timing, occurrence, or traffic state. In this paper, we present a novel approach for timetable rescheduling by introducing the concept of archetypical infrastructure pieces (AIPs): frequently occurring parts of the infrastructure. We consider three AIPs outside station areas, ranging from (i) double-track corridors between two double switches without, and (ii) including stops, to (iii) multi-track corridors with stops. For each AIP, a machine-scheduling based mathematical model is presented. Additional service constraints can be included to retrieve more practicable results, or to improve passenger experience. Extensive experiments show that the models outperform heuristics representative for dispatchers' decision-making by effectively balancing between re-timing, re-ordering, stop-skipping, and cancelling trains. We estimate that disruptions on about 50% of the Belgian railway network outside of station areas, can be considered using our three AIP models. Dispatchers could employ the models by characterizing the disruption and the infrastructure around it with a limited set of parameters. This approach allows to combine the models’ merit of efficiently balancing between measures, with the dispatcher’s knowledge on the surroundings of the corridor, and passenger expectations.

SESSION 12B: 13:50-14:50 ENERGY SAVING 2

Assessment of energy and emissions saving solutions in urban rail-based transport systems

Mohammad Hassan Davoudi Zavareh and Stefano Ricci

Global warming and climate change are indisputable theories. Since the Industrial Revolution, the mean temperature of the planet has increased by 1°C. Now, temperatures are approaching a higher stage of +1.5°C and the attention is on both CO2 emissions and energy consumption. Transportation is a major component of the environmental impact, accounting for approximately 30% of air pollution and energy consumption. Due to the rapid urbanization in the EU, with an estimated 74.3% of the population living in cities, forecasted to rise to 80% by 2050, urban mobility is dramatically increasing its relevance. Therefore, a reduction in energy consumption and pollutant emissions is a crucial factor to consider in developing urban transportation and particularly rail-based systems, able to provide energy saving transport services by improving urban environment. Several methods and techniques are under development to improve the energy performance of Light Rail Transport (LRT), which spread from different typologies of power supply to improving energy efficiency. The purpose of this paper is to start from the last developments and innovative energy sources for LRT systems. The focus is on two parts: a) trams running on Hydrogen in parallel with on board batteries with energy saving control techniques, b) potential renewable energy sources to meet power demand. The comparison is with traditional power sources and equipment (e.g. Catenary-based). The methods, based on selected indicators, are under development and test by calculations and simulations with reference to the case study of the new tramlines in the city of Brescia (Italy).


Junjie Lou, Xuekai Wang, Shuai Su, Tao Tang and Yihui Wang
With the increase of the operating mileage, a large amount of energy consumption generated by metro systems needs to be taken seriously. One of the effective ways to reduce the energy consumption is to collaboratively optimize the driving strategy and train timetable by considering the regenerative energy (RE). However, the dimensionality and computational time will increase accordingly in optimization as the number of operating trains rises. With the intention of tackling this problem by efficiently reducing dimensionality, the energy-efficient metro train operation problem is optimized in this paper by applying the discrete differential dynamic programming (DDDP) approach. Firstly, the model calculating the net energy consumption that takes into account the RE is formulated. Then, the optimization model will be transformed to a discrete decision problem by using Space-Time-Speed (STS) network methodology, and the corresponding solution will be obtained through the DDDP based algorithm. Finally, two case studies will be conducted in a metro network to illustrate the effectiveness of the proposed approach.

**Real-time micro-scheduling of trains to improve line flows and energy efficiency**

Peter Pudney, Amie Albrecht, Peng Zhou and Ajini Galapitage

Energy-efficient driving strategies are often disrupted by train separation constraints, particularly when there are short time headways between trains and some trains are delayed. When a train encounters a restrictive signal it will usually have to slow significantly, which disrupts efficient driving and introduces delays that can propagate back through the network.

Driver Advice Systems (DAS) can help trains follow a schedule precisely, and at the same time save energy. Connected Driver Advice Systems (C-DAS) extend this capability by adding communication with a central control system, which can provide real-time updates to individual train schedules in response to disruptions on the network.

In this paper, we use examples from a long-haul freight line and from an intercity passenger line to show how small adjustments to train schedules can be used to ensure safe separation of trains while minimising energy use, for trains travelling along a line between junctions.

We consider a pair of trains travelling along a line between junctions. First, we calculate independent energy-optimal driving strategies for each of the two trains. Next, we identify time intervals where the separation is less than the required separation distance. We then search for timing constraints that satisfy the separation constraints and for which the combined energy use of the two trains is minimised. This will result in smoother, more efficient train flows by avoiding encounters with restrictive signals.

**SESSION 12C: 13:50-14:50 NETWORK AND LINE PLANNING 2**

*Optimization of Train Line Plan for Public Holidays of High-Speed Railway*

Lei Nie, Zhenhuan He, Linqi Zhang, Jiabao Liu and Peiwen Han

With the rapid development of high-speed railway in China, train line planning encounters more challenges for holiday operations. Compared with weekdays, the number of high-speed railway passengers increases sharply during holidays and the spatial distribution of the passenger trips is diverse in different days. Thus, how to optimize holiday train line plan (HTLP) for high-speed railway to meet the fluctuation of passenger demand is becoming more and
Optimizing the Train Stopping Patterns on Long Distance High-Speed Rails
Ruoxi Xu, Lei Nie, Huiling Fu and M. Rapik Saat

For long distance high-speed rails, designing trains using different stopping strategies that satisfy both long and short distance travel need is a difficult task. Limiting the number of train stops to reduce travel time conflicts with the goal of increasing passengers’ opportunity to gain direct connections. In addition, long trains with frequent stops occupy too much route capacity, while disconnected short trains make passengers to transfer. To handle the trade-offs, this paper presents a mixed integer linear programming model that determines optimal combinations of train stopping patterns, and we particularly consider the practice that many long trains use skip-stopping strategy. The objective of the model minimizes time loss and transfer time of passengers. Specifically, we intend to run fast trains between major stations, such that travel time of many passengers with long distance trips can be shortened; meanwhile, to operate a certain number of short trains with dense-stopping or all-stopping patterns so as to ensure connectivity level between non-major stations and passengers can have frequent direct or transfer train options. We design a genetic algorithm procedure to manage real-size instances. We have tested our model and algorithm for the Beijing-Guangzhou high-speed rail line in China, which is a 2,298 km line with 36 stations. Numerical results indicate that our approach improves the travel efficiency of passengers compared with an existing train stopping schedule. We also explore the trade-offs among different train stopping strategies and their impact on travel efficiency of passengers.

An Assessment of Virtual Integration for Passenger Rail Services in Great Britain
Sultan Alsaedi and John Preston

Infrastructure management and railway undertakings were organisationally separated in Great Britain as a result of the 1993 Railways Act. However, this vertical separation has proved problematic, not least in terms of assessing the trade-offs between capacity utilisation and performance in terms of reliability and punctuality. A possible solution is virtual integration where an alliance is formed between the infrastructure manager and the dominant railway undertaking. The first such alliance in Great Britain was between Network Rail and South West Trains (SWT) and ran from 2012 to 2015. This paper undertakes a statistical analysis of public performance measures and cancelled and significantly late services for SWT and two comparator railway undertakings, Govia Thameslink Railway (GTR) and Southeastern. There are

more important. Meanwhile, the objectives of reducing the railway operation cost and ensuring the similarity between the holiday and the weekday line plan should be considered. Nowadays, HTLP is usually made by manually adjusting train formation and adding extra trains based on weekday line plans, which have low flexibility and adaptability to satisfy holiday’s passenger demand. This study mainly focuses on the optimization of HTLP based on weekday line plans using a theoretical method to improve the adaptability and benefit of line plans. Compared with the holiday line plans in real-world, our experimental results show that our optimized HTLP has less train operation cost and more similarity with the weekday line plans. And the service level of high-speed railway is also improved. Based on the experimental results, the effectiveness of our proposed model and solution method has been proved. The proposed mathematical optimization model and method can be used to improve the holiday line plan of high-speed railway.
no indications that virtual integration led to an improvement in the performance of SWT services but some indication that deteriorations were less than those for GTR, but this could be explained by other external factors. Overall, there is no clear indications that there were changes in punctuality and reliability trends for SWT as a result of virtual integration. Thus performance did not present a reason to end the virtual alliance between NR and SWT but nor did it provide reasons for continuing.

**SESSION 13A: 15:20-16:20 DELAY ANALYSIS AND PREDICTION 3**

**Investigating the effect of trackwork on punctuality of Swedish railways: analysed by using real train traffic data**

Saba Soltani, Nils O.E. Olsson, Lena Winslott Hiselius and Carl-William Palmqvist

The main purpose of this study is to develop an understanding of the effect of trackwork on train punctuality. The study is also a pilot on combining railway traffic data and maintenance data for analytical purposes. This type of analysis can show how different types of trackwork influence punctuality.

Previous studies on this subject have mainly utilised causes of delay data. In this study we have found methods to strengthen such analyses also by taking into account the high-resolution data available from registered records of train movements. The current study illustrates how such time data can be utilised in order to enhance the decision support system for maintenance.

A data processing method is used to identify the affected lines. A search engine is designed in order to correlate the two datasets (including train traffic data and trackwork data) and to extract the required data for the analysis. Through the overlap between the duration of trackwork and the delay in departure time, it is demonstrated that it is possible to combine railway infrastructure data with train traffic data.

As a result of this analysis, it is discovered that for railway traffic, in general, trackwork contribute, in fact, to a minor part of all causes of delays. However, a relatively large share of the trackwork was related to train delays. Another important finding from this study is that, when trackwork are conducted, it is a high probability that they will cause delays in train schedules and these delays are relatively large too.

**The Disruption at Rastatt and its Effects on the Swiss Railway System**

Beda Büchel, Timothy Partl and Francesco Corman

A railway track near Rastatt, Germany, lowered on 12 August 2017 and caused a complete blockage of a sector of a major rail corridor, which lasted until 1 October 2017. This track closure had severe effects on the railway freight and passenger transport. This work investigates the effects on the Swiss railroad network, using openly available realized operation data. The behavior of the delays before, during and after the disruption is investigated on three different levels. First, the delay of arriving trains to Basel SBB, as it can be seen as the input delay into the Swiss railway system. Secondly, it is investigated how the delay evolves on the Swiss intercity and interregional lines in short distance (i.e. first stop) and thirdly how this delay evolves over the course of the lines. The results display a consistent improvement of punctuality during the disruption period, which however decreases when considering stations farther away from Basel SBB. This can be explained by the fact that during the disruption period, trains arriving from Germany at Basel SBB exhibit, due to the shorter running distance, significantly lower delays than during other periods. The improved punctuality is therefore a
result of a reduced delay propagation of the trains arriving from Germany. The effects of this severe and long lasting disruption can be quantified even in some spatial and temporal distance. It can be used as an example to test theoretical models, which forecast delays, or examine train network complexity and interconnectivity.

**Mining Train Delay Propagation Pattern from Train Operation Records in a High-Speed System**

*Ping Huang* and *Chao Wen*

This study aims to investigate delays, delay increases, and delay recovery characteristics, by using statistical methods to clarify delay propagation patterns according to historical records of the Wuhan-Guangzhou high-speed railway (HSR) in China in 2014 and 2015. Specifically, we examined arrival and departure delay duration distributions and used heatmaps to demonstrate the spatiotemporal frequency distribution of delays, delay increases, and delay recovery, and the heatmaps clearly show hot spots (coordinates with high frequencies) in a timetable. Then, we separated delays as discrete intervals according to their severity, and analyzed the delay increasing frequency and the delay increasing severity within each interval, so as to clarify the relationships of delay increasing probability and delay increasing severity with delay extents. Next, we investigated the observed delay recoveries and prescheduled buffer times at (in) station (section), which demonstrate the recovery ability of each station and section. Finally, to understand the key influencing factor of delay propagation, we analyzed the relationship between capacity utilization and delays, delay increases, and delay recoveries, by examining their Pearson correlation coefficients. These indicate that delay frequencies and delay increasing frequencies with Pearson correlation coefficients as high as 0.9 are highly dependent on capacity utilization. The uncovered delay propagation patterns can enrich dispatchers’ experience, and improve their decision-making ability during real-time dispatching in HSR.

**SESSION 13B: 15:20-16:20 PLANNING POLICIES**

**Pricing of Commercial Train Paths Using Societal Costs**

*Abderrahman Ait-Ali*, *Jennifer Warg* and *Jonas Eliasson*

On deregulated railway markets, efficient capacity allocation is important. We study the case where commercial trains and publicly controlled traffic ("commuter trains") use the same railway infrastructure and hence compete for capacity. We develop a method that can be used by an infrastructure manager trying to allocate capacity in a socially efficient way. The method calculates the loss of social benefits incurred by changing the commuter train timetable to accommodate a commercial train path request and based on this calculates a reservation price for the train path request. If the commercial operator’s willingness-to-pay for the train path exceeds the loss of social benefits, its request is approved. The calculation of social benefits takes into account changes in commuter train passengers’ travel times, waiting times, transfers and crowding, and changes in operating costs for the commuter train operator(s). The method is implemented in a microscopic simulation program, which makes it possible to test the robustness and feasibility of timetable alternatives.

We show that the method is possible to apply in practice by demonstrating it in a case study from Stockholm, illustrating the magnitudes of the resulting commercial train path prices. We conclude that marginal societal costs of railway capacity in Stockholm are considerably higher than the current track access charges.
A mixed method for railway capacity allocation
Emanuel Broman, Jonas Eliasson and Martin Aronsson

As railway markets are increasingly deregulated, coordinating and prioritising between capacity requests becomes more complex. Conventional administrative procedures are often based, explicitly or implicitly, on prioritising criteria, which make them insufficient to differentiate between competing operators with similar services. An allocation method that improves social welfare would be desirable, but calculating welfare requires information that is typically commercially sensitive, such as number of passengers, fares and cost structures, making such an approach difficult to implement.

This paper describes the respective virtues and challenges of different types of allocation methods in the context of a deregulated market with mixed traffic and government-owned tracks. Three broad groups of allocation methods are described: commercial traffic with long planning horizons, traffic organised by public traffic agencies, and short-term traffic. We then outline an allocation method that better meets the requirements of a deregulated market. It is a mixed method, which uses an auction-like mechanism to allocate pre-defined paths to commercial operators on specified, capacity-constrained lines. The value of capacity for non-commercial public transport is assessed through social cost-benefit analysis (social CBA) of timetables. These social CBA results then decide the access charges for commercial operators.

Train Slots: A Proposal for Open Access Railways
Martin Scheidt

This paper seeks a concept to include fixed-interval paths with manageable train slots to satisfy the flexible needs of freight traffic in a strict fixed-interval passenger timetable. The primary method is constituted by literature review and theoretical slot construction. The terms timetable and railway operation are specified and illustrated. Different levels of timetables will be discussed and further developed. Two concepts, slots and pulses, are described together with precondition and modelling to accomplish a mixed timetable level for flexible freight traffic and fixed passenger traffic. Finally, a comparison of the timetable levels with the rail freight corridor Rhine-Alpine is presented. In conclusion, three points for further research are made, and an experiment is suggested to validate the result in the future.

SESSION 13C: 15:20-16:20 ROBUSTNESS 2
Fact-checking of timetabling principles: a case study on the relationship between planned headways and delays
Fabrizio Cerreto and Megan Holt Jonasson

Railway schedules are often planned after timetabling principles derived from practical experience and based on the macroscopic limitations of a system, rather than the microscopic conflicts inherent in its signaling system. This inaccuracy in planning principles can lead to infeasible timetables, which induce delays and thus reduce the service reliability of railway transport. The objective of this paper is to support the design of fact-based timetables by introducing a systematic analysis of historical data from operations on the Danish railway, which includes testing the principles used in the timetable design, specifically regarding the
allocation of headway time, and identifying possible improvements to the scheduling of trains according to their specific characteristics. The data records used in this analysis are generated by the signaling system and the automatic train detection system. The records state the scheduled and realized times of each train at every timing point on the network, as well as, categorical information about the trains and the measuring points. The timestamps are rearranged by an automatic algorithm to calculate the scheduled and realized running times, the scheduled and realized headways at the timing points, and the change in deviation between consecutive timing points for each train run. The relationships between these factors are then analyzed statistically to identify the adjustments that can be made to the timetabling principles to reduce the generation of secondary delays in operation and to improve the possibility of delay recovery under disturbed operation.

Study on Station Buffer Time Allocation According to Delay Expectation
Xiong Yang, Yafei Hou, Li Li and Chao Wen

Trains are inevitably subject to interference from the external environment and internal systems during operation, leading to delays and conflicts. In this regard, there are usually buffer times allocated at (in) the station (section) in the train timetable, to recover delays. Most of the existing methods that deal with the buffer time allocation mainly consider the length of the section and the traffic density. These methods usually fail to consider the impact of the actual delay of trains, and the buffer time allocation (BTA) is unreasonable. The integration of the actual delay effects into the BTA needs to be resolved. Based on this, in this work, a delay time distribution model was established, and the models were compared according to the standard error of each parameter in the model. Subsequently, based on the delay distribution, a BTA model with weighted average delay expectation time as the objective function was constructed in which the weight coefficients were determined based on the delay strength, and the model was solved by a mathematical analysis method. Different allocation models were designed for different ranges of the total buffer time values. Finally, taking the Dutch railway network trunk section Maarssen–Utrecht Centraal (Mas–Ut) as an example, the results show that the buffer time after redistribution of the BTA model reduces the expected delay time in the segment by 5.25% compared with the original buffer time of the station, indicating that the BTA is reasonable.

Connectivity Reliability on an Urban Rail Transit Network From the Perspective of Passengers’ Travel
Jie Liu, Qiyuan Peng, Jinqu Chen and Yong Yin

In the context of the urbanization and the development of Urban Rail Transit (URT). The reliability of URT network is getting attention. The connectivity reliability is the basis of it. Three indicators are constructed to measure the connectivity reliability of URT network from passengers’ tolerable travel paths, passengers’ travel efficiency and passengers’ travel realization on URT network, respectively. The tolerable coefficient which is the ratio of passengers’ tolerable travel time and shortest travel time of all connected paths is proposed and added to evaluation indicators to reflect passengers’ choice behaviour of travel paths. Based on the maximum impact of passengers, ratio of affected passenger volume (RPV) is proposed to identify the important stations. The AFC data, train running time data are used to calculate the passenger volume and passengers’ tolerable travel paths in Wuhan subway.
Finally, the connectivity reliability of Wuhan subway network is analysed through simulate attack stations. The results show that the identification methods of Degree Centrality (DC), Betweenness Centrality (BC) and ratio of affected passenger volume (RPV) can effectively identify the important stations on connectivity reliability of Wuhan subway. In particular, the method of RPV can identify the important stations that can influence the passengers’ travel realization in URT network most. In addition, attacking stations has greater impact on the passengers’ travel paths choice than passengers’ travel efficiency and travel realization.

WEDNESDAY, JUNE 19

SESSION 15A: 08:30-09:30 TIMETABLING 4

Improvement of maintenance timetable stability based on event specific flexibility assignment in track choice PESP

Raimond Wüst, Stephan Bütikofer, Severin Ess, Claudio Gomez, Albert Steiner, Marco Laumanns and Jacint Szabo

In the operational management of railway networks, an important requirement is the fast adaptation of timetable scenarios, in which operational disruptions or time windows with temporary unavailability of infrastructure, for instance during maintenance time windows, are taken into consideration. In those situations, easy and fast reconfiguration and recalculation of timetable data is of central importance. This local and temporal rescheduling results in shifted departure and arrival times and sometimes even in modified stop patterns at intermediate stations of train runs. In order to generate reliable timetabling results it is a prerequisite that train-track assignments, as well as operational and commercial dependencies are taken into consideration. In order to refer to the right level of detail for modelling track infrastructure and train dynamics in the computer aided planning process we present a generic model that we call Track-Choice FPESP (TCFPESP), as it implements suitable extensions of the established PESP-model. We show, how the service intention (the data structure for timetable specification) together with resource capacity information entered into a standard timetabling tool like Viriato can be utilized in order to configure the TCFPESP model.

In addition, we are able to calculate quantitative performance measures for assessing timetable quality aspects. In order to achieve this we present a method for evaluating travel times based on passenger routings and a method for evaluating timetable robustness based on max-plus algebra. This approach supports the planner to generate integrated periodic timetable solutions in iterative development cycles and taking into account intervals for local maintenance work.

Multi-objective Optimization of Train Timetable in Urban Rail Transit Network under Uncertain Demand

Zhenyu Han, Dewei Li, Baoming Han, Shangbin Ning, Yonghao Yin and Xinlei Dong

It is critical to design train timetables in urban rail transit network that can not only meet the daily time-dependent passenger demand, but also meet the passenger demand with day-to-day variations as well as remain stable and regular in a long term. The existing studies are not deep enough in uncertain-demand network-level train timetabling problem. Furthermore, the most studies concentrated on the passengers’ cost and neglected the operation companies’ cost. This study proposes two mixed-integer linear multi-objective models under uncertain
demand in rail transit network. The first one is on line level and the second one is on network level. Based on the perspective of both passengers and operation companies, the objective function is expressed as the weighted summation of average waiting time, final retention ratio and train services’ quantity. The uncertainty of train services quantity, the restriction of train services capacity and the transfer behaviour between lines are also taken into account. A scenario-based stochastic programing approach is applied to handle the models, which takes the passenger demand in a number of random selected days as a set of scenarios. A case study is presented to testify the effectiveness of the models and the efficiency of the approach. The results show a decline in general objectives during the multiple planning days. It suggests that the proposed models can keep balance between service quality and service cost in the long-term practice.

**A new approach to periodic railway timetabling**

*Gert-Jaap Polinder, Marie Schmidt and Dennis Huisman*

One of the criteria to judge a timetable is what passengers think of it, and an operator has to take this into account when designing a timetable. We study this problem in a case study from the Netherlands, where on part of the network the frequency of trains has increased recently. We formulate a model that integrates passenger routing and timetabling in order to find timetables that are good for passengers. This can be used for studies by railway operators, and by infrastructure managers to decide where to invest in new infrastructure.

**SESSION 15B: 08:30-09:30 FREIGHT TRAFFIC PLANNING 3**

**Scheduling and Routing Roaming Conductors to Support Single-Person Crew Operations on North American Freight Railways**

*Zezhou Wang, Darkhan Mussanov and C. Tyler Dick*

Train crews are a considerable expense for North American freight railways. Unlike many railway operations in Europe and other countries, freight railways in the United States must operate mainline trains with two-person crews (engineer and conductor). Besides human factors and safety concerns, the need for two crew members to perform work events en route, such as serving mainline customers, presents an obstacle to reducing labour costs by adopting single-person crews. To overcome this obstacle, railroads have proposed to operate each train with a single-person crew and replace the on-board conductors with “roaming conductors” who travel in highway vehicles and assist different trains with work events. The objective of this study is to determine the feasibility of replacing conventional on-board conductors with roaming conductors by solving the problem of optimally assigning train work events to roaming conductors. Various routing and scheduling approaches are developed to minimize the number of roaming conductors for a given operating plan. The results of Monte Carlo simulations show that based on different performance standards and practical assumptions in model parameters, the total number of roaming conductors will be less than the number of on-board conductors required for two-person crews. Depending on the operating conditions, roaming conductors can facilitate a net decrease in operating personnel (and associated decrease in labour costs) while still executing all required freight train work events. The scheduling algorithms developed through this research can help railroad practitioners determine where roaming conductors may be a feasible alternative to two-person crews.
Investigating Highway-Rail Intermodal Terminal Capacity Relationships via Simulation
Wesley Chen, Michael Pugh and C. Tyler Dick

As the largest single source of freight rail revenue, intermodal transportation of shipping containers and highway trailers by rail currently accounts for over one half of the total carloads hauled by Class 1 railroads in North America. A growing demand for freight transportation, along with record levels of North American intermodal rail traffic, has strained the capacity of the intermodal terminals dedicated to transloading containers and trailers to and from the rail mode. Since intermodal terminal capital and operating costs are substantial and greatly influence the competitiveness of intermodal by rail relative to other modes, railroads desire to optimize the utilization and capacity of existing facilities before investing in new construction. Although intermodal terminal capacity depends on a number of interrelated factors, current approaches to estimate intermodal terminal capacity rely on a combination of practitioner experience, historical trends and a limited number of single-factor capacity relationships. To provide industry practitioners with a better understanding of intermodal terminal capacity, this research investigates relationships between various capacity factors and intermodal terminal characteristics via simulation. A simulation model of a domestic inland intermodal terminal is developed using AnyLogic® software and used to test different facility layouts and operating scenarios. Preliminary results suggest that additional factors and interactions not considered by current capacity approaches may constrain intermodal terminal capacity and create congestion during periods of peak demand. It is anticipated that the final results will provide practitioners with new relationships to better evaluate the capacity of existing and proposed intermodal terminals.

Optimization Model for Multi-Stage Train Classification Problem at Tactical Planning Level
Ivan Belošević, Yun Jing, Miloš Ivić and Predrag Jovanović

Multi-stage train classification is a complex marshalling procedure that could be applied for simultaneous multi-group train formation. Simultaneous train formation is capable of processing a large volume classification insensitive on the number of outbound trains. Through multi-stage classification, wagons are moved several times to achieve desired outbound train sequences. The main optimization issue refers to finding a balance between the number of sorting steps and the total number of wagon movements. The optimization of the classification schedule could be addressed at different levels of the yard planning hierarchy. In this paper we develop mathematical formulation and two different heuristic algorithms to support tactical decisions for the multi-stage train classification problem. The main optimization issue refers to the allocation of tracks for performing multi-stage train classification minimizing annual operating costs. In order to validate the mathematical formulation and evaluate the efficiency of the proposed optimization model, we conduct computational tests and case study experimentations based on infrastructural and operational conditions applied in Belgrade marshalling yard in Serbia.

SESSION 15C: 08:30-09:30 DELAY ANALYSIS AND PREDICTION 4
Statistical Modeling of the Distribution Characteristics of High-Speed Railway Disruptions
Ping Huang
Studies on the spatiotemporal distribution and duration characteristics of railway disruptions are very significant for the advanced prediction of disruption and development of real-time dispatch strategies. In this study, historical disruption records of some Chinese High-Speed Railways (HSRs) lines from 2014–2016 were used to investigate the distribution characteristics of railway disruptions. The spatiotemporal probability distribution of four railway lines were calculated and their hotspots (coordinates with high probabilities) and coldspots (coordinates with low probabilities) were revealed using heatmaps. Furthermore, all the disruptions were classified into seven clusters based on their causes, and statistical analysis was carried out on each cluster. In addition, three right-skewed distribution models, namely Log-normal, Weibull, and Gamma distributions, were used to fit the duration of each cluster to uncover its duration regularities. Finally, goodness-of-fit test was performed on the models using the Kolmogorov-Smirnov method, indicating that the duration of each classified disruption can be estimated using a Log-normal distribution function. The obtained spatiotemporal probabilities and duration time distribution models thus can be further applied into estimating the occurrence and duration of railway disruption in real-time dispatching to help dispatchers make advanced decisions.

Evaluation of Travel Time Reliability using “Revealed Preference” Data & Bayesian Posterior Analysis
Sida Jiang, Christer Persson and Karin Brundell-Freij

In Swedish context, the value of delay is deemed equalling to the value of travel time reliability (VoR), which mostly derived from Stated Preference (SP) studies. According to our knowledge, there are several issues with the SP method for obtaining VoR, for example, its deficiency in harmonizing the stated choices with the actual choices. On the other hand, Revealed Preference (RP) data from ticket sales has its limit in socioeconomic information of travellers and scenario variation. This project aimed to use a RP method to estimate VoR from several selected railway corridors, with Bayesian posterior analysis to infer socioeconomic differences between passengers given on their actual choices.

The data in the study are from two sources, ticket sales data from a major passenger operator SJ, and data on train movements from Trafikverket’s (Swedish Transportation administration) TFÖR database. Both data sources are for the whole year 2009. The data includes 60,545 individual observations on traveler’s route choice for two specific trip relations. The chosen trip relations are long-distance non-commuting trips with travel distances between 200 and 250 kilometers.

The project is a “proof-of-concept” for possible use of ticket sales data for the estimation of VoR. We can conclude that the estimated VoR – 1.13 times value of travel time, is in compliance with results from previous international studies using SP and/or RP data. The simulated distribution of VoR from posterior analysis also clearly indicates a bimodal pattern of valuing travel reliability, probably due to socio-economic characteristics or trip purposes.

Dwell Time Delays for Commuter Trains in Stockholm and Tokyo
Carl-William Palmqvist, Norio Tomii and Yasufumi Ochiai

The paper analyses dwell time delays for commuter trains in Stockholm and Tokyo. In both cities, small dwell time delays of at most five minutes make up around 90% of the total delays. Therefore, it is valuable to understand and deal with these disturbances. To this end, we use
high resolution data on dwell times and passenger counts from both countries over the last several years. We find that these data alone can explain about 40% of the variation in dwell time delays and produce simple models which can be used in practice to assign more appropriate dwell times. A change in the congestion rate of 10%, or 15 passengers per car, in Tokyo translates to a delay of about one second. For every 10 remaining passengers per car in Stockholm, the delay increases by about one second, and one boarding or alighting passenger per car corresponds to about 0.4 seconds of delay. We also find that trains in Tokyo are much more congested than in Sweden, and that at most stations in the latter, the exchange of passengers is quite small. In both cities, the range of dwell time delays is quite narrow, with between 40 and 50 seconds separating the 5th and 95th percentiles. This indicates further that most delays, by far, are very small, and that even small adjustments to dwell times can make a big difference in the overall picture. To facilitate such improvements, key stakeholders and practitioners are closely involved with the research.

**SESSION 17A: 10:40-11:20 TRAFFIC MANAGEMENT 5**

*Interlocking System Based on Concept of Securing a Train Travelling Path*
*Tetsuya Takata, Akira Asano and Hideo Nakamura*

In recent years, the environment of railways and the systems such as CBTC (Communication Based Train Control) have been changing. To respond the changes and the needs of customers, a unified train control system (UTCS) has been developed to realize a system that evolves with customers.

Previous type systems consist of independent components such as ATC (Automatic Train Control) system, electronic interlocking system, and facility monitoring system, and there are a complicated overlap of system configurations and functions and difference in concept between the systems. On the other hand, the integrated train control system consists of horizontal layers such as function layer, network layer, and terminal layer. Therefore, the system has been developed to make it simple with no unnecessary redundancy and evolving to meet the needs of customers. In this paper, we explain a method that realizes the interlocking function in the function layer based on the concept of “securing a train travelling path” including path blocking and routing, and evaluate the safety of the method using STAMP/STPA.

**Applied Timetabling for Railways: Experiences with Several Solution Approaches**
*Julian Jordi, Ambra Toletti, Gabriele Caimi and Kaspar Schüpbach*

As part of the smartrail 4.0 program, SBB is focusing with the project TMS (Traffic Management System) on algorithmic supported, optimized and integrated capacity planning. For solving this problem, we have experimented with different approaches from the literature and have compared their quality and performance for our specific instances. In this contribution, we present the results of this comparison and discuss how we want to use this for having the best possible solution for our ambitious goal.

**SESSION 17B: 10:40-11:20 ROLLING STOCK SCHEDULING AND MAINTENANCE 2**

*Strategic Planning of Rolling Stock Rotations for Public Tenders*
*Timo Berthold, Boris Grimm, Markus Reuther, Stanley Schade and Thomas Schlechte*
Since railway companies have to apply for long-term public contracts to operate railway lines in public tenders, the question how they can estimate the operating cost for long-term periods adequately arises naturally. We consider a rolling stock rotation problem for a time period of ten years, which is based on a real world instance provided by an industry partner. We use a two stage approach for the cost estimation of the required rolling stock. In the first stage, we determine a weekly rotation plan. In the second stage, we roll out this weekly rotation plan for a longer time period and incorporate scheduled maintenance treatments. We present a heuristic approach and a mixed integer programming model to implement the process of the second stage. Finally, we discuss computational results for a real world tendering scenario.

**Train-set Assignment Optimization with Predictive Maintenance**  
Meng-Ju Wu and Yung-Cheng Lai

Train-set is one of the most expensive assets of a railway system. Hence, the efficiency of train-set utilization is an important objective pursued in practice. An efficient train-set assignment plan, including the assignment of utilization paths and maintenance tasks, should be designed and implemented in accordance with demand (utilization schedule) and maintenance requirements. Previous studies have adopted the fixed periodic maintenance (PM) strategy for the train-set assignment problem. However, the difference in the reliability of train-set is not considered in this strategy. Maintenance planners have to manually adjust utilization and maintenance tasks on the basis of experience. This study proposes an optimization process for assigning train-set to utilization paths and maintenance tasks in accordance with the predictive maintenance strategy (PdM) with trainset-specific reliability models. Results of the empirical study demonstrate that the developed process with predictive maintenance can assign utilization paths and schedule maintenance tasks to each trainset efficiently and reduce the total cost by over 11% compared with the PM-only strategy. Adopting this process can help planners improve the efficiency and reliability of train-set utilization.

**SESSION 17C: 10:40-11:20 PASSENGER FLOW ANALYSIS 3**

**A Model of Passenger Distribution on Metro Platforms Based on Passengers’ Boarding Strategies**  
Jiping Fang, Fujiyama Taku, Howard Wong and Xin Chen

With a growing demand for metros in metropolises, such as London in the UK, network capacity should be ideally improved further. For metro lines with already high-frequency services, it is the train dwell time that determines the number of trains per hour in peak times. Passenger distribution on the platform affects the train dwell time, thereby the metro network capacity. This study has developed a model of passenger distribution on the metro platform. Not only are the layouts and congestion on the platform at the stations where passengers board the trains considered in the model, but also the passengers’ origin-destination pairs, the waiting time and the platform layouts at the stations where passengers alight. Loadweigh data (the weight of passengers in each train car), which is an economical alternative to the traditional manual counting, has been used to calibrate the model. The model is validated by the Chi-Square goodness of fit test and performs well to reflect the causes of passenger distribution on the platform. A case study of 8 stations on Hammersmith&City line of London Underground shows that there were on average 16% of passengers in the morning peak chose boarding cars on the platforms based on the locations of the platform exits or interchange passageways at
the stations where they would alight. The results would be useful for the metro operation planners and station staff to take measures to manage passenger distribution on the platform.

A traveller perspective on railway punctuality: Passenger loads and punctuality for regional trains in Sweden
Ida Kristoffersson and Roger Pyddoke

This paper examines the extent to which delayed trains are also trains with more passengers. The paper uses unique passenger load data about regional trains in Sweden and combines this with Swedish delay statistics for the same train numbers and from the same time periods. Results show that trains with high passenger numbers are not delayed to a greater extent compared to trains with fewer passengers. Train punctuality is thus a good indicator of traveller punctuality in this case. These results also suggest that long boarding and alighting times due to high passenger numbers are not a main cause of delays, possible causes of delays are instead external factors such as track maintenance or dense train movements. Therefore, this result suggests that policy makers should look further into the latter causes. Furthermore, the paper also compares the share of travellers and trains that are more than half an hour late, i.e. that are significantly late. These differences are also small but larger than for the less delayed trains. For one of the railway lines, trains with high passenger loads are more than proportionally hit by long delays. Such cases suggest that train control priorities could be re-examined with more focus on improving the service for railway travellers.

SESSION 17D: 10:40-11:20 HYPERLOOP
Hyperloop and Swissmetro technology assessment and system analysis
Ingo Hansen

The Hyperloop concept, pod competitions and actual development plans have recently attracted much publicity. The technologies of the most serious vacuum tube transport projects, Hyperloop by E. Musk (SpaceX) and Swissmetro by M. Jufer et al. (EPF Lausanne), are assessed with regard to their principal aims, system approaches and technical feasibility. The vehicle design, propulsion, levitation and practical capacity of the two (near) vacuum tube transport projects are compared with existing railway and Maglev trains. The potential high-speed long-distance travel demand is assessed for “Swissmetro” corridors in Europe and the proposed Hyperloop link Los Angeles- San Francisco in California, respectively. Major technical and environmental alignment and construction constraints for the design of the tubes, guideway and stations are identified. The consistency and safety of possible operating programs for the investigated corridors of Swissmetro and Hyperloop, are evaluated respectively. Finally, the main barriers and needs for further research and development are identified.

ASSESSMENT of POTENTIAL COMMERCIAL CORRIDORS for HYPERLOOP SYSTEMS
Jeanne-Marie Dalbavie, Marc Delas and Thierry Boitier

This study has led to the elaboration of a proposed methodology used to select and rank the most attractive corridors for the implementation of first commercial vacuum-tube train (or hyperloop) lines for passengers. From a list of the most populated cities all over the world, it has been possible to sort out the possible transport connections that could be travelled by hyperloop pods without having to
build a tunnel or crossing a conflict area. Then, an evaluation of all selected corridors has been performed on the basis of defined classification criteria. Important parameters characterizing the potential of a corridor have been identified during the research: the number of air passengers on the corridor, the nature of the competitive transport infrastructure, the GDP per kilometre and the topography along the route. Some other minor criteria have also been used, in order to elaborate a robust tool which can be a good help for investors and decision makers. All selected corridors have been ranked, resulting in a short list of the 250 most attractive corridors for the implementation of first commercial lines.

This study presents a proposal for the ranking of the most promising corridors. It should be followed by proper feasibility studies and ridership calculations.
DID YOU KNOW...

The city name Norrköping is pronounced [ˈnɔːrˌtʃɜːpɪŋ], that is, the k sounds like ch (for example in the word chair). The ö you may recognize from other Germanic languages, where it is sometimes written as oe.

In Swedish norr means north and köping may be translated as market town, giving the interpretation of Norrköping as “Northern market town”. Some 120 years ago the Swedish adventurer Sven Hedin returned from an expedition to China, where he had found out that the meaning of Beijing (literary “the northern capital”) is very similar, and so the nickname Beijing (Swedish: Peking) for Norrköping was born.

“Sweden’s Manchester”, which is another nickname for Norrköping, comes of course from the notable textile industry.

NORRKÖPING’S TRAMWAY

Norrköping’s tramway has been in service since 1904, and is, along with the larger Gothenburg tram network, one of only two city-center tramways in Sweden that survived the national switch to right-hand traffic in 1967. The network today consists of two lines with a total length of 18.7 Km. The vehicle fleet contains modern Flexi Classic wagons from Bombardier and older Düwag GT8 wagons, bought in second-hand from the German city Dessau and modernized, for example with a low-floor section in the middle.

THE SWEDISH KRONA AND ITS HUNDREDTHS

The currency in Sweden is called krona (plural kronor, sign Kr, code SEK), and its hundredths öre. In practice, however, the last öre coin (50 öre) was suspended in 2010 and since then one krona is the smallest unit for cash transactions. Nonetheless, most stores still use two decimals in the prices. If you pay by credit card you will be charged the precise amount, and otherwise the total amount is rounded to nearest full krona.
HAPPY MID-SUMMER!

Right after RailNorrköping 2019, on Friday June 21st, the Swedes celebrate “midsommar” (the summer solstice). In Sweden, that day is almost as important as Christmas. There are traditional celebrations with fiddle and accordion music and dances around the midsummer tree, and the food being served includes fresh potatoes and herring. (Don’t forget to bring your “smörkniv”, the special butter knife which you find in your conference bag!) Normally, we can also harvest the first strawberries to this day. Some “snaps”, flavored brandy, is also part of the tradition, and the legend says, if you pick seven different flowers and put under your pillow when going to bed, you will dream about your future partner We wish all participants a happy mid-summer, Glad Midsommar!

ARE YOU STAYING IN NORRKÖPING OVER THE SUMMER?

In July, Norrköping will host the largest orienteering competition, O-Ringen. A village of tents will pop up in the city and more than 17,000 people of all ages will run through the forests equipped with maps and compasses to find their way. For the very best runners there will be a sprint competition in central Norrköping where the world’s elite try to find their way through the campus and other locations you get to know during the conference.

Photo: Thor Balkhed, LiU