10th International Conference
on Railway Operations Modelling and Analysis (ICROMA)

RailBelgrade 2023

Book of Abstracts

April 25th - 28th, 2023

ORGANIZED JOINTLY BY THE INTERNATIONAL ASSOCIATION OF RAILWAY OPERATIONS RESEARCH (IAROR) AND UNIVERSITY OF BELGRADE - FACULTY OF TRANSPORT AND TRAFFIC ENGINEERING

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BOOK OF ABSTRACTS

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Sanjin Milinković

Belgrade, 2023

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Preface

The idea of organizing the biennial International Conference on Railway Operations Modelling and Analysis (ICROMA) is to strengthen the international transfer of knowledge and co-operation in the railway planning and operations research area. The cycle of ICROMA conferences started in Delft in 2005 and continued in Hannover (2007), Zürich (2009), Rome (2011), Copenhagen (2013), Tokyo (2015), Lille (2017), Norrkopping (2019) and Beijing (2021).

ICROMA conferences are organised by the International Association of Railway Operations Research (IAROR) attracting researchers, consultants, and industrial practitioners to meet, present their latest research, exchange know-how, and discuss current developments and applications.

Preface to the 10th ICROMA - RailBelgrade 2023

Those who have been in touch with ICROMA conferences in the past know well that it is not just a cycle of scientific conferences but a forum established to trace the latest developments with the aim of inspiring research on future railways. On this occasion, we thank the authors who contribute papers dealing with various aspects of railway operations, modelling and analysis. We thank all of the participants for presenting their views and discussing delivered solutions for railway transport problems. Among 139 papers submitted originally, 125 papers have been accepted (113 research papers and 12 industrial papers). All papers have undergone rigorous peer review. In this process, the Organizing Committee has strong support from the Scientific Advisory Committee (SAC) and reviewers. The Scientific Advisory Committee consisted of 50 researchers from more than 20 countries, and the pool of reviewers was extended by other 82 active IAROR members and senior researchers. We appreciate their dedicated work in ensuring the quality of the conference program.

Besides the effort of authors, reviewers, and members of SAC and Organizing Committee, we have received help from our sponsors and supporters. We express sincere gratitude for the outstanding support provided by company Stadler as a General sponsor of this conference. We thank Gold sponsors: Trenolab, OpenTrack Railway Technology, MSC - Mediterranean Shipping Company and IVU Traffic Technologies, and all other sponsors and supporters. This conference could not be successfully organized without their help and support.

This year ICROMA is celebrating a jubilee. We enjoy the pride and happiness of hosting the 10th International Conference on Railway Operations Modelling and Analysis which will take place in Belgrade with the participation of the world's leading institutions, hosted by University of Belgrade - The Faculty of Transport and Traffic Engineering.

Belgrade, April 2023

On behalf of the Organizing Committee
Ivan Belošević, Conference Chair

Conference Programme

Tuesday, April 25th		
11:00-12:00	Mini Course I (Room 128): Crew Scheduling (Dennis Huisman)	
12:10-13:10	Mini Course II (Room 128): Capacity and Performance of Freight Railway Yards and Terminals (C. Tyler Dick)	
13:10-14:00	Lunch Break	
14:00-15:00	Mini Course III (Room 128): Multimodal Transportation System Simulation (Carlos Azevedo)	
15:10-16:10	Mini Course IV (Room 128): Railway Operations Modeling with Petri Nets (Sanjin Milinkovic)	
16:30-18:30	**Welcome Reception**	
Wednesday, April 26th		
08:15-09:15	REGISTRATION	
09:15-10:15	OPENING CEREMONY (Room 125)	
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10:30-11:00	**KEYNOTE (Room 125):** MILP Reformulations for Train Timetabling and Dispatching: Recent Advancements (Carlo Mannino)	
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11:30-11:50	*86*	Fangsheng Wang, Pengling Wang, Zixuan Zhu, Xiaofang Xiao and Ruihua Xu. Robust optimization of train timetable with short-turning strategy considering uncertain passenger demand and vehicle selection
11:50-12:10	*107*	Berenike Masing, Niels Lindner and Christian Liebchen. Periodic Timetabling with Integrated Track Choice for Railway Construction Sites
12:10-12:30	*39*	Wenyu Wang, Fangsheng Wang, Feng Zhou, Ling Hong and Ruihua Xu. Train dwell time analysis for urban rail transit stations based on random forest algorithm: A case study on Beidajie station of Xi'an Metro
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11:30-11:50	*68*	Michael Nold and Francesco Corman. Challenges and opportunities for the railway system in 2050: results from a survey of experts
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13:00-13:20	7	Tommaso Bosi, Federico Bigi, Andrea D'Ariano and Francesco Viti. The Shunt-In Shunt-Out Problem in Rail Freight Transport: an Event-Based Simulation Framework for Sustainable Rolling Stock Management
13:20-13:40	32	Elias Dahlhaus. Generalized Train Marshalling from Practical View, Development of the Sorting Requirements and Heuristics
13:40-14:00	101	Niloofar Minbashi, Jiaxi Zhao, C. Tyler Dick and Markus Bohlin. Application of Simulation-assisted Machine Learning for Yard Departure Prediction
14:10-15:10	Session 2.4A (Room 128): Timetabling II	
14:10-14:30	16	Zhiyuan Yao, Lei Nie, Zhenhuan He and Jingzhe Zhou. A Rolling Horizon Approach to Dense and Heterogeneous Train Timetabling with Skip-Stop Strategy
14:30-14:50	24	Ambra Toletti, Florin Leutwiler, Jullian Jordi, Gabrio Caimi and Francesco Corman. Timetabling for Railways in Practice: Examples of Real-world Constraints
14:50-15:10	33	Alexander Kuckelberg. Microscopic routing for mixed granularity routing requests
14:10-15:10	Session 2.4B (Room 325): Driver Advisory Systems and ATO	
14:10-14:30	37	Peiran Ying, Xiaoqing Zeng, Andrea D'Ariano, Dario Pacciarelli and Haifeng Song. Energy-efficient High-speed Train Driving Considering Neutral Zone and Time window
14:30-14:50	21	Ziyulong Wang, Egidio Quaglietta, Maarten Bartholomeus, Alex Cunillera and Rob Goverde. Conflict-free train path planning using ATO timing points
14:10-15:10	Session 2.4C (Room 326): Rail freight transport II	
14:10-14:30	97	Yuan Chen, Minyi Cai, Haodong Li and Jiaqi Ding. Data-driven based circular train design of railway freight transportation
14:30-14:50	45	Siqiao Li, Xiaoning Zhu, Pan Shang and Li Wang. Multi-objective Express Shipment Service Network Design for High-speed Railway Networks
14:50-15:10	145	Vladan Nikolic. Strategies for the Improvement of Rail Freight Transport Between the Republic of Turkey and Republic of Serbia: A Case Study Using A'WOT Model
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15:10-15:50	30	Tamme Emunds, Mariia Anapolska, Christina Büsing and Nils Nießen. Developing Event-Action Network Heuristics for Real Time Traffic Management in Urban Railway Transit

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15:10-15:50	57	Milan Dedík, Zdenka Bulková, Lumír Pečený and Martin Vojtek. Potential of the long-distance railway transport routes in the post-pandemic period in Europe
15:10-15:50	60	Yingsi Huang, Yuyan Tan, Yafeng Ma, Zizhen Zhao and Yaxuan Li. Railway Passenger Kilometers Forecasting with Combined Multi-Grey Neural Network Model
15:10-15:50	59	Atieh Kianinejadoshah and Stefano Ricci. Combined Lines-Nodes Capacity Assessment in Freight-Passengers Complex Railway Networks
15:10-15:50	66	Ruyue Zhao, Lingyun Meng, Nikola Bešinović, Jianrui Miao, Xiaojie Luan, Yihui Wang and Zhengwen Liao. Dynamic Train Priority Rescheduling Model with Mixed Passenger and Freight Traffic using A Rolling Horizon Solution Approach
15:10-15:50	103	Viera Klasovitá and Francesco Corman. Line Planning for Time-Varying Passenger Demand in Railways
15:10-15:50	117	Fabrizio Cerreto, Paola Pellegrini, Rémy Chevrier and Fabrizio Tavano. Assessing self-organization algorithms for railway traffic: the selection of three case studies for the SORTEDMOBILITY research project
15:10-15:50	120	Matea Mikulčić, Ivica Ljubaj and Zvonimir Zelenika. Initiating Wireless Railway Network Planning with FRMCS in Croatia
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15:50-17:10	Session 2.5A (Room 128): Timetabling III	
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16:30-16:50	13	Tao Han, Yuguang Wei, Huaixiang Wang and Yang Xia. Optimization of train timetabling for Container Trains under Passenger Transport Mode in Railway Corridors
16:50-17:10	98	Xiajie Yi, Grégory Marlière, Paola Pellegrini, Joaquin Rodriguez and Raffaele Pesenti. Coordinated train rerouting and rescheduling in large infrastructures
15:50-17:10	Session 2.5B (Room 325): Digital Automated Train Operation	
15:50-16:10	5	Zishuai Pang, Liwen Wang, Li Li and Qiyuan Peng. A Hybrid Machine Learning Model for Train Dwelling Time Prediction Addressing Passenger Flow Fluctuations
16:10-16:30	26	Adrian Wagner, Ulrich Pernull, Philipp Graf and Frank Michelberger. Impact of the Digital Automatic Coupling for single wagonload transport
16:30-16:50	77	Dimitris Kouzoupis, Ishan Pendharkar, Jonathan Frey, Moritz Diehl and Francesco Corman. Embedded Model Predictive Train Control
16:50-17:10	43	Steffen Schäfer, Lucas Greiner-Fuchs, Tobias Hofmeier, Philipp Koch and Martin Cichon. Virtual Validation Method of Automated On-Sight Driving Systems for Shunting Operations

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15:50-16:10	129	Geordie Roscoe, Matthew Parkes and C. Tyler Dick. Evaluating the Potential for Platoons of Self-Propelled Autonomous Railcars (SPARCs) to Provide Short-Haul Intermodal Service on Low-Density Rail Corridors
16:10-16:30	12	Andrew Nash, Giorgio Medeossi and Mike Bagshaw. Agile Simulation: An approach for increasing optimisation in railway planning.
16:30-16:50	125	Zhuang Li, Hongxiang Zhang, Wen Wen, Bisheng He, Yuan Wang and Gongyuan Lu. Evaluating Car-to-Train Assignment Strategies for the Railway Marshalling yard using a Multi-Agent Simulation Approach
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09:20-09:40	36	Nicola Coviello, Giorgio Medeossi, Thomas Nygreen, Paola Pellegrini and Joaquin Rodriguez. A multi-objective framework for strategic railway timetabling: integration of ant colony optimization and mixed integer linear programming
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09:00-10:00	Session 3.1B (Room 325): Rolling stock and crew scheduling II	
09:00-09:20	73	Shan Jiang, Yongxiang Zhang, Qiyuan Peng, Tianyin Zhao, Tao Feng and Jiawei Lu. Real-time train timetable and rolling stock circulation plan rescheduling in an urban rail transit network: an integrated optimization approach
09:20-09:40	102	Mariana De Almeida Costa, Tiago Alves, António Ramos Andrade and Francesco Corman. A Hybrid Bogie Maintenance Approach to Optimize Railway Fleet Availability
09:40-10:00	99	Arturo Crespo Materna, Cedric Steinbach, Andreas Oetting and Shanqing Chai. Towards a Generic Heuristic Approach for the Real-Time and Automatic Schedule Adjustment
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09:00-09:20	71	Peiran Han, Lingyun Meng, Nikola Bešinović, Xiaojie Luan, Zhengwen Liao, Jianrui Miao and Yihui Wang. Optimizing Resource Planning in Shunting Yard with Constraint Programming
09:20-09:40	40	Predrag Grozdanović, Miloš Nikolić, Milica Šelmić and Dragana Macura. Prediction of the Freight Train Energy Consumption with the Time Series Models
09:40-10:00	8	Gaurav Kumar and Akhilesh Kumar. Optimization Models for Rail Freight Operators: A Case Study of Indian Special Freight Train Operator
10:00-10:15	Coffee Break	
10:15-11:15	Session 3.2A (Room 125): Timetabling IV	
10:15-10:35	58	Zhiwen Jiang, Yun Bai and Zongran Li. Cross-line Train Service Planning considering Passenger Travel Demand after Large Events
10:35-10:55	48	Jianhao Ge, Pengling Wang and Xiaofang Xiao. Timetable Optimization for Sharing-Corridor Metro Lines under Virtual Coupling
10:55-11:15	142	Tianqi Li, Lei Nie and Rob Goverde. Periodic train timetable expansion: An integrated model of multi-period train service selection and rolling stock circulation with time-varying passenger demand

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10:15-10:35	28	Nattanon Luangboriboon, Marcella Samá, Andrea D'Ariano and Taku Fujiyama. Assessment of Passenger Management Strategies within Public Transport Terminals
10:35-10:55	65	Yasufumi Ochiai. An algorithm to estimate dwell time of trains based on association rules for real-time train traffic prediction
10:55-11:15	115	Ruben A. Kuipers, Natchaya Tortainchai, Neba C. Tony and Taku Fujiyama. Dwell-time Station-Service analysis using Rasch analysis technique
10:15-11:15	Session 3.2C (Room 326): Rail governance and economics	
10:15-10:35	3	Igor Domeny, Anna Dolinayova, Michal Valla and Zuzana Zidova. The Issue of Fares Measures in Passenger Railway Transport in the Context of a Modal Share of Railway Transport
10:35-10:55	132	Predrag Jovanović, Miloš Nikolić and Dragana Macura. Selection of the Optimal Railway Public Services Regarding External Costs and Transport Market Structure
10:55-11:15	140	Nikola Ristić, Pavle Kecman and Predrag Jovanović. Optimal Allocation of Waste Transfer Facilities for Infrastructure Manager
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11:20-11:40	35	Yuma Mouri, Kazushige Yonemoto and Norio Tomii. Evaluation of Delay Reduction Measures based on Visualization of Historical Train Traffic Records and Data-Driven Simulation
11:40-12:00	131	Fabrizio Cerreto. Station capacity assessment with probabilitstic approach: a case for Ringsted station in Denmark
11:20-12:00	Session 3.3B (Room 325): Train delay prediction and conflict detection	
11:20-11:40	11	Ping Huang, Thomas Spanninger and Francesco Corman. A train delay propagation model based on Bayesian networks for probabilistic delay prediction
11:40-12:00	41	Florian Hauck, Albrecht Güth, Natalia Kliewer and David Rößler. Applying Generative Adversarial Networks to Generate Synthetic Train Trip Data for Train Delay Predictions
11:20-12:00	Session 3.3C (Room 326): Railway traffic management and rescheduling II	
11:20-11:40	64	Ranfei Zheng, Jianrui Miao, Zhengwen Liao, Xiaojie Luan, Hongjun Ning, Lingyun Meng, Nikola Bešinovic and Rongbin Liu. A high-speed railway traffic control approach with local-rerouting and adaptive rescheduling range
11:40-12:00	137	Xiaoyu Hou, Xiaojie Luan, Zhengwen Liao, Jianrui Miao and Lingyun Meng. Dispatching Strategy for Cross-bureau and Cross-line Trains in Railway Network Operations
12:00-12:15	**CLOSING CEREMONY (Room 125)**	
12:15-13:00	Lunch Break	
13:15-17:00	**Technical Visit**	

Location

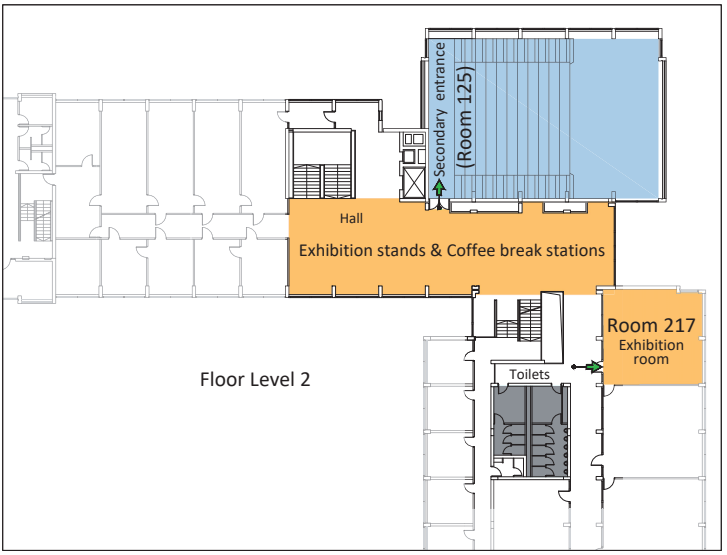
RailBelgrade 2023 will be held at University of Belgrade – The Faculty of Transport and Traffic Engineering. All activities (except for the conference dinner and technical visit) will take place in the faculty building, specifically:

Parallel sessions of the conference will be held in rooms 125, 128 (floor level 1), 325 and 326 (floor level 3).

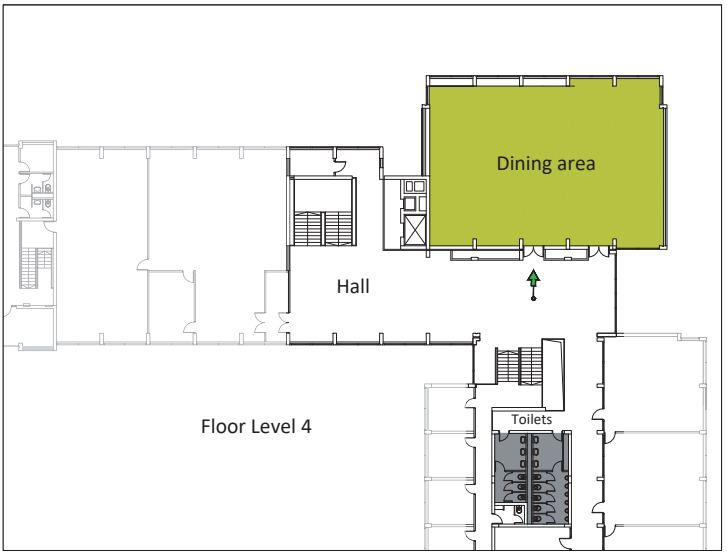
Keynote speeches will be held in room 125 (floor level 1).

Mini course will be held in room 128 (floor level 1).

Exhibitors and poster presentations area will be located in a hall (floor level 2).



Welcome reception and conference lunches will take place in a dining area (floor level 4).



Venue and Contact Information:
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Keynote Speakers

MILP Reformulations for Train Timetabling and Dispatching: Recent Advancements

Carlo Mannino
Professor
SINTEF Digital, Oslo; University of Oslo, Norway

Abstract:

Train timetabling and train dispatching are two very related and central problems in the railways industry. They share a common core problem, that is routing and scheduling trains through a rail network, respecting business rules, while ensuring all safety rules. Mixed integer linear programming (MILP) models for such core problem have been studied and developed for at least a half a century. Nevertheless, you could count the actual real-life implementations on the fingers of one hand. The main reason for this gap between theory and application is simply that the standard models are extremely hard to solve for the size and complexity of real-life instances of some practical interest. Luckily, recent decomposition approaches have proven to be very effective in shortening computational times and reducing this gap. In this keynote we present some recent developments in Benders' decomposition and reformulation for train timetabling and dispatching. The main idea of this approach is to drop many variables and complicating constraints and replace them with suitable (and hopefully few) constraints in the remaining variables. The new constraints are in correspondence with the directed cycles and trees of a certain graph associated with the instance of train routing and scheduling. In a few recent articles, it is shown how this decomposition approach (or its derivations) can lead to significant speed-ups in the solution process. Successful real-life applications are also presented.

About Carlo Mannino:

Carlo Mannino is senior scientist in the department of mathematics and cybernetics at SINTEF DIGITAL, Oslo, and part-time full professor at the University. He has over 70 publications, including several top journals in mathematical optimization and operations research. His scientific research was focused on mathematical programming approaches for scheduling and network optimization. He has also been interested in practical applications of operations research. He received the EURO Excellence in Practice Award 2009 and the AIRO Best Application Paper award in 2014 for his work on railways optimization, and the INFORMS Best Telecommunication Paper Award 2014. He is associate editor of Operations Research.

High-Speed Rail Transport Systems: Analysing, Modelling, and Evaluating

Milan Janić
Research Professor,
University of Belgrade, Serbia

Abstract:

This keynote speech presents an approach to analyzing, modelling, and evaluating three HS (High Speed) rail-based transport systems: High-Speed Rail (HSR), Trans Rapid Maglev (TRM) and Hyperloop (HL). A methodology consisting of two components has been developed for this purpose. The first component includes analytical models of indicators of performances for the systems to be analyzed. Given the characteristics of infrastructure and rolling stock representing the systems' infrastructural and technical/technological performances, the indicators of operational, economic, environmental, and social performances have been defined and modelled respecting the interests and preferences of particular actors/stakeholders involved. These actors/stakeholders comprise users/passengers, the systems' transport operators, local, regional, and national authorities and investors, and community/population members. The other component includes the SAW (Simple Additive Weighting) method which uses these indicators as criteria for a multi-criteria evaluation of the systems. The methodology has been applied to a real case study assuming that the three HS systems operate exclusively according to the "what-if' scenario approach. The results indicate that, under the given conditions, the HL emerges as a preferable alternative compared to its TRM and HSR counterparts.

About Milan Janić:

Dr Milan Janić is a transport and traffic engineer and planner. At present, he is a Research Professor at the Faculty of Traffic and Transport Engineering, University of Belgrade, Belgrade, Serbia. Previously, he was Senior Researcher at the Transport & Planning Department of the Faculty of Civil Engineering and Geosciences and a Leader of the Research Program in the OTB Research Institute at Delft University of Technology (Delft, The Netherlands), Manchester Metropolitan University and Loughborough University (UK), and the Institute of Transport of the Slovenian Railways (Slovenia).
Dr Janić has been involved in many research and planning projects at both national and international scale for almost forty years. He has also published numerous papers in the peer-reviewed scientific and professional journals. In addition to contributing to

many edited books, he has been the author of ten book monographs, including: 'Resilience, Robustness, and Vulnerability of Transport Systems: Analysis, Modelling, and Practice'; 'System Analysis and Modelling in Air Transport: Demand, Capacity, Quality of Services, Economic, and Sustainability' 'Advanced Transport Systems: Analysis, Modelling, and Evaluation of Performances', 'Greening Airports: Advanced Technology and Operations', and the co-author of the book 'Transportation Engineering: Theory, Practice, and Modelling', 1st and 2nd Ed.).

As well, Dr Janić is and used to be a member of Editorial Boards of several transport research-related journals, and the international associations and conferences. Dr Janić was also among Stanford's World's Top two percent scientists during the period 2019-2020.

Resilience in Railway Transport Networks: From Concepts to Applications

Nikola Bešinović
Head of the Chair of Rail and Public Urban Transport,
Technical University of Dresden, Germany

Abstract:

The rising transport demand increases the congestion in railway networks and thus they become more interdependent and more complex to operate. At the same time, an increasing number of disruptions due to system failures as well as climate changes can be expected in the future. As a consequence, many trains are cancelled and excessively delayed, and thus, many passengers are not reaching their destinations which compromises customers need for mobility. In this talk, we introduce the concepts of resilience, particularly focussing on railway transport systems. A brief overview of internal and external disruptive events will be presented. We then elaborate on different approaches for assessing and improving resilience of the railway transport system including their specific advantages and disadvantages. Diverse aspects will be covered including planning and real-time applications covering different resilience stages. Finally, several examples will be demonstrated such as monitoring the system's resilience based on the historical disruption data, assessing vulnerability of the networks including the infrastructure impacted by floods, and responding and recovering from the system's failures.

About Nikola Bešinović:

Nikola Bešinović is a Head of the Chair of Rail and Public Urban Transport at Technical University of Dresden, Germany. Previously, he was a Lecturer and Researcher at Delft University of Technology, The Netherlands. He has a PhD in Railway Transport (2017) from Delft University of Technology, and a MSc in Operations Research (2011) and BSc in Railway Transport and Traffic Engineering (2009) both from University of Belgrade. Nikola's research develops analytics and optimization methodologies to promote efficient, reliable and sustainable railway transport systems. His main focus is on resilient transport concepts, combining AI and optimization, and improving capacity of infrastructure and multimodal operations. Nikola received several scientific awards, including the Young Railway Operations Researcher Award from IAROR, the TRAVISIONS Young Researcher Award, and the Best IEEE ITS Dissertation Award. He is a Chair of INFORMS Railway Application Section.

Abstracts

Session 3.2C: Rail governance and economics
Submission type: Research paper
Presentation type: Oral
Paper ID: [3]

The Issue of Fares Measures in Passenger Railway Transport in the Context of a Modal Share of Railway Transport

Igor Domeny, Anna Dolinayova, Michal Valla and Zuzana Zidova.

University of Žilina

The passenger railway market sector is in general known as an example of a regulated market. To achieve the sustainable and green mobility available to everyone regardless of their social situation, it is necessary to regulate the fares by the responsible public authority. In the European Union, there is not a uniform approach to the fare's measures, and they vary from country to country. Some countries have also introduced free transport or significant discounts for selected groups of passengers, such as children, students, and pensioners, which has brought up a question if such a strong measure is efficient from the social point of view. On one side, this approach would change the transport behaviour of socially disadvantaged groups of population, on the other side, it can lead to an outflow of fully paying passengers due to a lower comfort and quality of services. In this paper, we present an overview of social discounts in railway transport in European Union member states and evaluate the impact of selected fares measures on the transport performances and changes in a modal split. For this evaluation, we use the methods of trend modelling and forecasting.

Keywords
Passenger transport, Fares, Social discounts, Exponential smoothing

Session 3.1A: Railway capacity II
Submission type: Industrial paper
Presentation type: Oral
Paper ID: [4]

Understanding Railway Line Capacity

Alex Wardrop

Independent Railway Operations Research Consultant

There are transport planners, who are not railway operations analysts, but who still need to know about railway operational matters. This paper is thus meant for them with simple, but realistic, metrics so that they are able to carry out preliminary project evaluations before more detailed examinations are carried out. They need to understand line capacity, a railway's key property. If there is surplus line capacity then train flows can be increased, but they have to be the "right" train flows in order to do so. So if trains run at different speeds in the flow, then line capacity might be lost and a project might need extra track to recover. However, if a project entails increasing the numbers of similar trains, it may only be necessary to augment signalling. This is still not a costless exercise but is generally less expensive than building additional tracks. Nevertheless, it is assumed that we actually know what the current line capacity is and the extent to which it can be exploited. For non-railway practitioners, this paper simplifies how line capacity can be estimated without recourse to detailed analytical analysis or train performance simulation, so that they can apply the methodology. It breaks down the analysis into plain track, junction and terminus signalling and introduces the impacts of station dwell and terminus layover times. It then uses the suburban railways of Wellington, New Zealand, as test beds for applying the methodology and understanding some of the complications of estimating real world line capacity.

Keywords
Headways, Junctions, Termini, Line Capacity, Suburban Railways

Session 2.5B: Digital Automated Train Operation
Submission type: Research paper
Presentation type: Oral
Paper ID: [5]

A Hybrid Machine Learning Model for Train Dwelling Time Prediction Addressing Passenger Flow Fluctuations

Zishuai Pang, Liwen Wang, Tianyin Zhao, Qiyuan Peng and Li Li.

Southwest Jiaotong University School of Transportation and Logistics

Train timetables and operations are restricted by the train running time in sections, dwell time at stations, and headways between trains. Accurate estimation of these factors is essential to decision-making during train delays. In the present study, we propose a train dwell time prediction model based on a voting mechanism and dynamic updating to address the challenges in the train dwell time prediction problem (e.g., dynamics over time and spatiotemporal relationships of factors). The voting mechanism in the present study is based on multiple base predictors, enabling the proposed model to integrate the advantages of the base predictors in addressing the challenges in terms of data attributes and data distributions. Then, considering the influence of passenger flow on train dwell times, we use a dynamic updating method based on exponential smoothing to improve the performance of the proposed method by considering the real-time passenger amount changes. Based on data from the Chinese high-speed railway line, the experimental results show that, due to its advantages over the base predictors, the voting mechanism can more accurately predict the dwell time at stations than its counterparts. Further, the experimental results exhibit that dynamic smoothing can significantly improve the accuracy of the proposed model during passenger amount changes.

Keywords
Train operations, Dwell time, Passenger flow, Voting mechanism, Dynamic smoothing

Session 2.3C: Rail freight transport I
Submission type: Research paper
Presentation type: Oral
Paper ID: [7]

The Shunt-In Shunt-Out Problem in Rail Freight Transport: an Event-Based Simulation Framework for Sustainable Rolling Stock Management

Tommaso Bosi[a], Federico Bigi[b], Andrea D'Ariano[a] and Francesco Viti[b].

[a] *Roma Tre University*
[b] *University of Luxembourg*

The European Union plans to double the freight rail traffic by 2050 both to cut pollution emissions and to mitigate congestion by shifting traffic from road to rail networks. One of the challenges is to minimize emissions and high costs associated with shunting yard operations while maintaining an acceptable service level. In this context, we propose an Event-Based Simulation Framework for wagon Shunt-in and Shunt-out operations. The Event-Based Simulation Framework exploits programming tools and a MILP model to minimize the number of Shunt-in and Shunt-out operations performed and, consequently, both strategic and tactical objectives such as the wagon fleet size, departure delays and emissions of shunting locomotives. Several versions of the MILP model are described based on the Shunt-in policy applied. Each Shunt-in policy has different criteria for wagon's choice and has shown a strong goal orientation. To test the MILP model's effectiveness, we have considered short and long-term real train timetables for freight trains in the Bettemburg Eurohub Sud Terminal (Luxembourg) and we have assessed different KPIs linked to tactical and strategic objectives. Computational results show that the criteria for choosing which wagons should be taken-out from the inbound train and should be inserted into the outbound train might significantly impact multiple rail system KPIs analyzed. The Event-Based Simulation Framework is part of the ANTOINE national project financed by CFL (Chemins de fer luxembourgeois) and is considered an add-on tool to Shunty, an industrial software project for rail decision-makers.

Keywords
Freight Rail Operation, Shunting Operation, Rolling Stock Maintenance, Multimodal Transport Systems, Decision Support System

Session 3.1C: Rail freight transport III
Submission type: Research paper
Presentation type: Oral
Paper ID: [8]

Optimization Models for Rail Freight Operators: A Case Study of Indian Special Freight Train Operator

Gaurav Kumar[a] and Akhilesh Kumar[b].

[a] *Indian Institute of Technology Kharagpur*
[b] *Indian Institute of Management Raipur*

Rail freight is crucial to any nation's economic development because it delivers efficient and cost-effective freight services. For strategic decision-making and operational policy development, rail freight operators (RFOs) should create relevant and integrated operations research models. This study combines the benefits of private investment in rolling stock and express transport services. This research involves resolving fleet planning difficulties for RFOs for moving rakes throughout the country via express or ordinary transport service at record transit times. First, we formulate a mixed-integer linear programming (MILP) mathematical model as an integrated model of optimal mixed fleet size, rake assignment, and rake scheduling for RFOs that maximizes revenue by incorporating both ordinary and express transport services. Furthermore, we propose a Two-phase Greedy Search Heuristic for larger and more complicated problems. The first phase determines the optimal number of rakes and rake types using a Mixed Fleet Size Heuristic. Then we tackle the rake assignment and scheduling issues by utilizing the Greedy Search Rake Schedular Heuristic and prior phase output. Moreover, with a mixed fleet size, rake assignment, and schedule, the model aims to explain how to achieve the optimal trade-off between freight prices, turnaround time, and ordinary-express service selection. A greedy search rake schedular heuristic for small and medium instances produced results almost as excellent as those achieved using an exact method (CPLEX). This heuristic technique produces near-optimal solutions for all large instances in very few seconds. Thus, RFOs' daily operations and future market potential can be better managed using these models.

Keywords
Mixed integer linear programming, Heuristics, Rail Freight Operator, Express freight transport service, Fleet Planning

Session 3.3B: Train delay prediction and conflict detection
Submission type: Research paper
Presentation type: Oral
Paper ID: [11]

A train delay propagation model based on Bayesian networks for probabilistic delay prediction

Ping Huang[a], Thomas Spanninger[b] and Francesco Corman[b].

[a] *Southwest Jiaotong University*
[b] *ETH Zurich*

In this study, train delay propagation was modeled by a stochastic model, called Bayesian networks (BN), for probabilistic delay prediction. The aim is to use the probability inference in the BN to quantify the probabilities of potential future situations by probabilistic prediction of train delays, given the stochastic essence of railway transport systems (e.g., the epistemic and aleatoric uncertainty in delay predictions). To overcome the drawback of the existing graph- or network-based train delay propagation models that were only built on train delays, we introduce three planned timetable-based parameters in the BN model to enable the proposed BN structure, called context-driven BN (CBN), to recognize the context information in train operation. The CBN model is calibrated on the train operation data from the Swiss railway network. The results show that the context information improves the accuracy and lowers the variance of the model, compared against the standard models without considering the parameters. In addition, the model is established based on updating time horizons (multiple updating time horizons form the prediction horizon), making it capable of performing short-distance (e.g., 5 or 10 minutes ahead) and long-distance (e.g., 1 hour ahead) predictions. Therefore, the CBN model is able to predict the delays (at each checkpoint) in the prediction horizon, and the prediction can be dynamically updated when train delays are observed over train operations. Finally, the model is based on the network-based model, making it remain the interpretable and easy-understanding quality of network- and graph-based models.

Keywords
Train delays, probabilistic prediction, context information, Bayesian networks

Session 2.5C: Railway simulation and digital twins
Submission type: Industrial paper
Presentation type: Oral
Paper ID: [12]

Agile Simulation: An approach for increasing optimisation in railway planning.

Andrew Nash[a], Giorgio Medeossi[b] and Mike Bagshaw[c].

[a] *St Poelten University of Applied Sciences*
[b] *University of Trieste*
[c] *MTR UK*

This paper defines agile simulation as embedding simulation experts into railway planning processes. It identifies five key advantages of agile simulation and recommends that railways use agile simulation to increase the effective use of simulation in all types of planning projects. The paper is based on the hypothesis that increasing the use of simulation would improve railway efficiency and service quality. The paper is based on experience operating London's Elizabeth line service since 2015.

Keywords
Simulation, Timetables, Strategic Planning, Elizabeth line, Agile Simulation

Session 2.5A: Timetabling III
Submission type: Research paper
Presentation type: Oral
Paper ID: [13]

Optimization of train timetabling for Container Trains under Passenger Transport Mode in Railway Corridors

Tao Han[a], Yuguang Wei[a], Huaixiang Wang[b] and Yang Xia[a].

[a] *Beijing Jiaotong University*
[b] *China Academy of Railway Sciences Corporation Limited*

The railway container system under passenger transport mode plays an important role in improving the efficiency of railway container transport in China and promoting the competitiveness of the railway in the market of high value-added freight market. With the aim of minimizing the total dwell time of trains, this paper optimizes the schedules for the passenger train-like container trains with different operation zones in railway corridors. Furthermore, we consider the specific assignment of containers to trains and ensure that the train dwell time at stations is sufficient to complete the container loading and unloading operations. A mixed integer linear programming model is formulated by considering whether the arrival time of the train is convenient for the clients to pick up the goods, the freight transit period and the allocation of the arrival-departure tracks. The proposed model is solved using the CPLEX solver. The numerical experiments were implemented on the Lianyungang-Alataw pass corridor to demonstrate the effectiveness of the proposed method.

Keywords
Railway container transport, Passenger transport mode, Train scheduling, China Railway Express

Session 1.3B: Train delay prediction
Submission type: Research paper
Presentation type: Oral
Paper ID: [14]

Transformeurs à Grande Vitesse

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[a] *Massachusetts Institute of Technology*
[b] *SNCF Réseau*

Robust travel time predictions are of prime importance in managing any transportation infrastructure, and particularly in rail networks where they have major impacts both on traffic regulation and passenger satisfaction. We aim at predicting the travel time of trains on rail sections at the scale of an entire rail network in real-time, by estimating trains' delays relative to a theoretical circulation plan.
Predicting the evolution of a given train's delay is a uniquely hard problem, distinct from mainstream road traffic forecasting problems, since it involves several hard-to-model phenomena: train spacing, station congestion and heterogeneous rolling stock among others. We first offer empirical evidence of the previously unexplored phenomenon of delay propagation in a railway network, leading to delays being amplified by interactions between trains. We then contribute a novel technique using the transformer architecture and pre-trained embeddings to make real-time massively parallel predictions for train delays at the scale of the whole rail network (over 3k trains at peak hours, making predictions at an average horizon of 70 minutes). Our approach yields very positive results on real-world data when compared to currently-used and experimental prediction techniques.

Keywords
operations research, complex systems, traffic forecasting, propagation forecasting, transformer model, delay propagation

Session 2.3A: Rolling stock and crew scheduling I
Submission type: Research paper
Presentation type: Oral
Paper ID: [15]

Asymmetric demand-oriented train scheduling and rolling stock circulation planning with skip-stop tactic: A Mixed integer linear programming approach

Zongran Li, Yao Chen, Yun Bai and Yaling Xiao.

Beijing Jiaotong University

The existing symmetric strategy, providing equal service frequencies in two directions, cannot adapt to the asymmetric passenger demand on metro lines. This study proposes an asymmetric strategy combing skip-stop tactics, which schedules more train services for the oversaturated-demand direction and executes some express trains for the undersaturated direction to accelerate rolling stock circulation. Meanwhile, we integrate the rolling stock circulation into the asymmetric demand-oriented train scheduling problem and formulate it as a mixed integer linear programming (MILP) model. Some realistic constraints including capacity limitation and the rigid first-come-first-serve (FCFS) principle are explicitly considered. Due to the model complexity, a decomposition method embedded with linear programming (LP) relaxation is developed. Based on given service frequencies, this method divides the original bi-objective model into multiple single-objective models and solves them directly by relaxing the rigid FCFS constraints. To further improve the solution efficiency in a large-scale instance, we also propose a decomposed-based model by solving the asymmetric schedule in each direction separately. Case studies verify the effectiveness of the proposed method. Compared to symmetric with all-stop strategies, our proposed asymmetric strategy can reduce passengers' total travel time by 5.24%, without increasing the operating cost.

Keywords
Metro line, Asymmetric passenger demand, Train scheduling, Skip-stop train, First-come-first-served principle

Session 2.4A: Timetabling II
Submission type: Research paper
Presentation type: Oral
Paper ID: [16]

A Rolling Horizon Approach to Dense and Heterogeneous Train Timetabling with Skip-Stop Strategy

Zhiyuan Yao, Lei Nie, Zhenhuan He, Jingzhe Zhou and Lu Tong.

Beijing Jiaotong University

As the passenger demand for high-speed railway continues to grow and calls for diversified and hierarchical train services, great challenges have been posed for railway companies to design a feasible timetable that can schedule the specified large number of train lines which are heterogeneous in terms of speed and origin-destination. To efficiently solve the train timetable of one day period, this paper designs a rolling horizon approach to split the whole period into several time slices based on which the timetable optimization is quickly performed. The interactions of trains among different time slices are carefully handled. Further, flexible skip-stop strategy is designed to improve the feasibility of train timetable. The proposed approach is tested on the real-world case study of China's Beijing-Shanghai high-speed railway with the practical line plan.

Keywords
Train timetabling, Skip-stop strategy, Rolling horizon approach

Session 1.3C: Energy saving in railways
Submission type: Research paper
Presentation type: Oral
Paper ID: [18]

Investigating freight train path inefficiency in view of reduction of pollutant emission

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[b] *State Key Laboratory of Road and Traffic Engineering, Tongji University*

Many freight trains are still diesel-powered, and their emission cannot be ignored. This research proposed a framework to evaluate the path inefficiency due to stops in the middle of their journeys and the associated emission from idling and reacceleration. The framework includes Number of stops, Stopping time, Stopping percentage, and was applied to integrated datasets from January to June 2022 in Great Britain. We found that each diesel freight train made on average 1.34 stops, with an average summed stopping times of 17.2 minutes and a stopping percentage of 6.89%. It was estimated that in that 6-month period, 53.1 ktonnes of CO_2 were emitted. Domestic intermodal accounted for 60% of total emissions. Early or late departure at the origin from the scheduled time may have affected journey time, but have not increased emission to a great extent. This framework could be used in the evaluation of railway timetables and operation management at the national level.

Keywords
Freight trains, Timetable path inefficiency, Stops and idling time, Commodity type analysis, Emission and environmental impact

Session 1.1C: Passenger assignment
Submission type: Research paper
Presentation type: Oral
Paper ID: [19]

Extracting Railway Passenger Demand Patterns from Origin-Destination Data for Developing Demand-Oriented Service Plans

Renate J.H. van der Knaap[a], Menno de Bruyn[b], Niels van Oort[a], Dennis Huisman[c] and Rob M.P. Goverde[a].

[a] *Delft University of Technology*
[b] *NS*
[c] *NS & Erasmus University Rotterdam*

Train passenger demand fluctuates throughout the day and week and these fluctuations are expected to increase due to the COVID-19 pandemic. In order to let train services, such as the line plan and timetable, match this fluctuating demand, insights are needed into how the demand is changing and for which periods the demand is relatively stable. Hierarchical clustering on origin-destination (OD) data is used to determine for each workday continuous time-of-day periods in which the passenger demand is homogeneous. The periods found for each workday are subsequently used as input in a clustering algorithm to look for similarities and differences between workdays. Both normalized and regular OD matrices are tested as input for the method. In normalized OD matrices, only the structure of the demand is captured, while in the regular OD matrices both the structure and the volume of the demand are included. The methods for finding homogeneous periods in demand during the day and week are applied to a case study covering a large part of the railway network in the Netherlands. We find large differences between the periods based on regular OD matrices and those based on normalized OD matrices. The periods based on regular OD matrices seem more appropriate to use as input for designing a service plan. Comparison of the periods over the week shows that mainly the peak periods on Friday are far away from Monday to Thursday, and hence could benefit from an altered service plan.

Keywords
Railway passenger demand patterns, Origin-destination data, Clustering, Homogeneous periods

Session 2.2B: Railway alignment and network design
Submission type: Research paper
Presentation type: Oral
Paper ID: [20]

Optimization of the Inspection Area Districting Plan for Comprehensive Inspection Trains

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The quality of the inspection area districting plan for the Comprehensive Inspection Trains (CIT) has a direct impact on the formulation of subsequent plans, which in turn affects the operational safety of the high-speed railway (HSR). However, it relies on manual programming and adjustment for long time, which makes it difficult to ensure the rationality and fairness of the districting plan. For solving this problem, we construct a mixed-integer linear programming model, which aims to minimize the task volume deviation among CITs and optimize the compactness of each CIT sub-network, comprehensively considering constraints such as line coverage integrity, inspection under up-to-speed conditions, line-vehicle special attribute matching, and inspection area connectivity. The model we design linearly expresses complex matching relations with downward compatibility characteristics, and gives a connectivity determination method under non-unique matching relations by constructing a multi-commodity network flow model. Finally, we improve the traditional ideal point method to linearize the bi-objective into single-objective, and design various test cases to analyze the effects of the input conditions on the solution quality and solution speed. The results show that the key factors affecting the quality of the districting plan are the heterogeneity of CIT speed levels and the compatibility of CIT with special lines, and conclude that the network size and the number of CITs have the most significant effect on the solution speed.

Keywords
Mixed-Integer Programming, Districting, Task Balance, Compactness, Connectivity

Session 2.4B: Driver Advisory Systems and ATO
Submission type: Research paper
Presentation type: Oral
Paper ID: [21]

Conflict-free train path planning using ATO timing points

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[b] *ProRail*

Automatic Train Operation (ATO) is a technology to support or automate train driving for increasing service punctuality, energy efficiency and rail infrastructure capacity. Conflict-free train path planning is crucial to the effective deployment of ATO, which allows ATO-equipped trains to operate according to schedule with different train driving strategies. As different train driving strategies lead to various passing times, current planning practice is inadequate to avoid route conflicts as it only sets target arrival or passing times at stops or major junctions. Therefore, conflict-free train path planning needs the definition of a Train Path Envelope (TPE) that contains time targets or windows defined at discrete locations called timing points to tolerate schedule deviations due to different driving styles. The number and location of the timing points, as well as the associated time targets or windows, is a decision problem. This paper proposes a framework to design a robust set of timing points and their associated time windows in a TPE to enable operational conflict-free train path planning against the driving strategies utilised. This framework relies on a Train Path Slot model which extends the definition of TPE from time windows at a discrete set of locations to an integrated blocking time stairway pattern continuously defined across all locations over a train route. The Train Path Slot model considers three relevant train driving strategies, i.e., energy-efficient driving with or without coasting as well as minimum-time driving considering slight delays. A Linear Programming model is formulated to compute the conflict-free Train Path Slots as constraints for train operation. To meet the optimised Train Path Slots, we analyse several possible sets of timing points in a TPE that are only located at stops or signal positions along the train routes. Those timing point sets are then compared in terms of total Train Path Slot overlap time, capacity, energy efficiency and driving performance indicators. Our research supports infrastructure managers in resolving the imminent problem of timing point determination and TPE computation to reach their capacity goals. At the same time, it allows sufficient driving flexibility for railway undertakings.

Keywords
ATO-over-ETCS, Automatic Train Operation, Train Path Envelope, Train driving strategies, Timing Point

Session 1.2C: Railway maintenance planning and scheduling
Submission type: Research paper
Presentation type: Oral
Paper ID: [23]

ACHILLES: Reducing Infrastructure Whole-Life Costs

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The ACHILLES research programme is a collaboration between six UK universities and the British Geological Survey, which aims to provide the tools to "assess, monitor, design and repair the performance of the ground" upon which infrastructure depends, to ensure that rail and other linear infrastructure provides "consistent, affordable and safe services, underpinned by intelligent design, management and maintenance." The research programme addresses three main challenges: (i) improved understanding of material and asset deterioration processes; (ii) improved understanding of asset performance, with and without interventions; and (iii) improved forecasting of asset and network behaviour, and decision support for interventions, identifying best-value intervention strategies. These challenges are met through four complementary workstreams: (i) Performance and Deterioration (PaD); (ii) Monitoring and Measurement (MaM); (iii) Simulation and Modelling (SaM); and (iv) Design and Decisions (DaD). This paper is focussed on the SaM and, especially, DaD workstreams. It describes the development of decision support to identify the earthworks maintenance and renewal strategies, and select the designs required, to reduce and ideally minimise the whole-life costs of individual assets, routes and networks. The work is based initially upon cuttings on Britain's Great Western Main Line railway between London and Bristol, whose individual and collective whole-life costs are being analysed to develop a route-level whole-life engineering cost model. The workstreams then extend to include the handling of uncertainty, environmental and passenger and freight end-user impacts, and the costs and potential benefits of additional asset condition data.

Keywords:
Railways, Earthworks, Climate change, Whole-life costs, Cost-benefit analysis

Session 2.4A: Timetabling II
Submission type: Industrial paper
Presentation type: Oral
Paper ID: [24]

Timetabling for Railways in Practice: Examples of Real-world Constraints

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We review some practical challenges when elegant mathematical models have to consider and correctly describe the wide range of possible situations present in reality. We specifically describe how a mathematical model in the state of the art could be expanded by ad hoc modelling of specific situations. This shows on the one hand the complexity of real life, the possibility to include special situations in existing models, and identifies a path for more realism in the models.

Keywords
Timetabling software, Real-world constraints, Railway scheduling, Swiss railway infrastructure managers

Session 1.2C: Railway maintenance planning and scheduling
Submission type: Research paper
Presentation type: Oral
Paper ID: [25]

Influence of different prioritization approaches of maintenance and replacement measures on station infrastructure quality

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In Germany, the station infrastructure is to be operated by DB Station&Service AG. That means that DB Station&Service AG is responsible for ensuring satisfactory infrastructure quality. Predefined quality targets for the infrastructure have been set with the federal government for this purpose. The quality of the station infrastructure assets is described by a nationwide grade that is formed by aggregating the grades of the individual infrastructure assets. In order to counteract age-related degradation of the assets, financial resources are available for their replacement and maintenance. Different strategies can be applied for the use of this budget. This includes, on the one hand, the distribution of the budget among the different types of assets and, on the other hand, the prioritization of the needs for measures. The influence of the different budget distribution and of different approaches for prioritizing the measures on the quality of the infrastructure assets is currently unknown and therefore needs to be analyzed and quantified. For this purpose, a model that maps the degradation of infrastructure assets and considers the effect of measures in a controllable way is developed so that a relationship between quality and budget can be established. Subsequently, the different budget allocations and prioritization strategies can be implemented and analyzed.

Keywords
infrastructure, degradation, stations, maintenance, quality measurement

Session 2.5B: Digital Automated Train Operation
Submission type: Research paper
Presentation type: Oral
Paper ID: [26]

Impact of the Digital Automatic Coupling for single wagonload transport

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In order to get more freight traffic on to the rails, it is necessary to optimize this transport mode and make it more attractive for the customers. But it is not only interesting from the customer's view that optimization in freight transport can make sense Various manual processes have a high physical demand on the employees. For example, coupling and uncoupling of wagons currently still requires the deployment of personnel in the track area. In the last few years, several initiatives have already dealt with the introduction of Digital Automatic Coupling (DAC). This paper deals with the effects that DAC can have on single wagonload traffic in Austria. At the beginning of the paper the different levels of a DAC are explained. Then various shunting processes are examined. For this purpose, two use cases are taken, where coupling is a relevant part. The first use case shows a train formation in a station. The second use case shows shunting train in industrial sidings. In both it can be presented that the DAC in level 4 lead to a significant time saving. But especially in the second use case it can also be shown that the coupling activity is only a minor part of the total process. However, this shows that the DAC can also serve as an enabler for further functionalities. And therefore, the other components can also be improved.

Keywords
Single wagonload traffic, Digital Automatic Coupling, shunting, freight traffic

Session 2.3B: Railway signalling and control systems
Submission type: Research paper
Presentation type: Oral
Paper ID: [27]

Lessons from ERTMS and PTC Implementation in Europe and the United States

Steven Harrod

Danmarks Tekniske Universitet

Railway signal systems in North America and Europe have a plan to replace old analog signal systems with digital signal systems. This paper explains the history and motivations for each continent, and the general technical and capability differences between the two signal systems. In general, North America revised their signal systems to respond to safety concerns, and Europe committed to replace their signals for operational reasons. The impact on freight traffic is documented for each continent, and success and failures discussed.

Keywords
ERTMS, PTC, Positive Train Control, Railway Signals, Industry 4.0

Session 3.2B: Passenger flows
Submission type: Research paper
Presentation type: Oral
Paper ID: [28]

Assessment of Passenger Management Strategies within Public Transport Terminals

Nattanon Luangboriboon[a], Marcella Samá[b], Andrea D'Ariano[b] and Taku Fujiyama[a].

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This paper addresses the problem of passenger flow management in major public transport terminals by proposing a new passenger modelling approach. While the flows of passengers in major transport terminals are in a discrete manner, existing tools generally view the passenger flows as continuous; hence, passenger management is currently done based heavily on the experience of station managers. This research proposes modelling the flows of passengers as discrete instead. The problem is modelled as mixed-integer linear programming (MILP) inspired by the alternative graph (AG) model. The case study results show that the model can be used to assess and compare passenger management strategies, for instance, the morning peak case study results show that 578s of conflict, which occurs in one strategy, can be traded off with 78s of total tardiness, by applying a different strategy. The proposed model can be used to support station managers in assessing complex situations before making management decisions.

Keywords
Passenger crowd management, Scheduling, Transport terminals, Station boarding control strategy, Platform announcement and loading

Session 1.2C: Railway maintenance planning and scheduling
Submission type: Research paper
Presentation type: Oral
Paper ID: [29]

The Bouquet of Features in Rolling Stock Rotation Planning

Thomas Schlechte[a], Christian Blome[b], Stefan Gerber[c], Stefan Hauser[b], Jens Kasten[b], Gilbert Müller[b], Christof Schulz[a], Michel Thüring[c] and Steffen Weider[a].

[a] *LBW Optimization GmbH*
[b] *IVU Traffic Technologies*
[c] *SBB Cargo*

Railway undertakings are facing rolling stock scheduling challenges in different forms - from rather idealized weekly strategic problems to very concrete operational ones. Thus, a vast of optimization models with different features and objectives exist. Thorlacius [2015] provides a comprehensive and valuable collection on technical requirements, models, and methods considered in the scientific literature. We contribute with an update including recent works. The main focus of the paper is to present a classification and elaboration of the major features which our solver R-OPT is able to handle. Moreover, the basic optimization model and algorithmic ingredients of R-OPT are discussed. Finally, we present computational results for a cargo application at SBB Cargo and other railway undertakings for passenger traffic in Europe to show the capabilities of R-OPT.

Keywords
rolling stock rotation planning, vehicle scheduling, layered graph algorithms, optimization, heuristic

Poster session
Submission type: Research paper
Presentation type: Poster
Paper ID: [30]

Developing Event-Action Network Heuristics for Real Time Traffic Management in Urban Railway Transit

Tamme Emunds, Mariia Anapolska, Christina Büsing and Nils Nießen.

RWTH Aachen University

A significant amount of public transportation in metropolitan areas worldwide is performed with urban railway transit. Millions of passengers rely on well-functioning, reliable and effective systems. As disruptions in rail-bound traffic are often hard to bypass, reactions to these disturbances have to be planned in order to reduce their impact on passengers.
This paper implements a decision support tool for the intraday railway rescheduling problem, finding possible schedule amendments to cope with already known future disruptions. These amendments aim to decrease the influence of disturbances on the quality of passenger service on a densely occupied metro line. For a given disrupted traffic, amendments are chosen which reduce the pre-defined penalties for deviations from the timetable of the line.
In this work, schedules and potential disruptions are modeled with the help of event-action networks. Solution strategies with different local search heuristics are presented and discussed. Furthermore, they are tested on infrastructure data of London's newly built Elizabeth line for different scenarios of traffic disruptions. Additionally, the potential of parallel computing implementations is explored. Our methods yield operational feasible solutions, and selected amendments achieve significant penalty reductions compared to an initial solution without any traffic management measures.

Keywords
rescheduling, transportation science, railway transportation, real-time traffic management, event-action network

Session 2.3A: Rolling stock and crew scheduling I
Submission type: Industrial paper
Presentation type: Oral
Paper ID: [31]

Rolling Stock Planning with Maintenance Constraints by a Rolling Horizon approach

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Swiss Federal Railways SBB

Special event traffic, holidays and construction work lead to frequent updates on the rolling stock plan at SBB. When planning for such events, the planner needs to simultaneously consider effective rolling stock use, timely maintenances for all rolling stock units, the topology of the track network as well as the use of valid train compositions at all times. Already ensuring timely maintenances is a complex problem: There are various types of periodic maintenances with different degrees of importance and dependencies between the different types. Moreover, maintenance planning is a shared responsibility of rolling stock and maintenance facility planners. A facility may require a certain unit to visit at a specific time. In this work, we introduce a rolling horizon model based on mixed-integer linear programming for aiding the planners in quickly finding effective plans. Our model allows re-planning a timeframe taking into consideration all relevant maintenance requirements. We model the rolling stock planning problem as a network flow where a unit of flow corresponds to one vehicle. The crucial idea of our formulation is to introduce a separate flow for each type of maintenance that encodes all its relevant constraints. The combined problem is then solved by coupling the individual flows. We report on the effectiveness of our approach using two real-world re-planning problems for two different fleets at SBB

Keywords
Rolling Stock, Maintenance Planning, Mixed Integer Linear Program, Rolling Horizon

Session 2.3C: Rail freight transport I
Submission type: Research paper
Presentation type: Oral
Paper ID: [32]

Generalized Train Marshalling from Practical View, Development of the Sorting Requirements and Heuristics

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In the first part of the paper, it is shown, how to develop the sorting requirements of a distributer train. It has to be defined the notion of a distribution plan. The distribution plan has to be transformed into a tree that defines the groups of cars that have to be put together. A group of cars may have subgroups. For some groups of cars, the subgroups have to appear in a fixed sequence. This leads to the introduction of directed PQ-trees. In the second part of the paper, we consider the problem to minimize the number off classification tracks to get the train sorted as required by the PQ-tree. In general, the problem is NP-complete, and the dynamic programming algorithm for an exact solution is exponential in the worst case. But it is shown that heuristics can be integrated into the dynamic programming algorithm that can make the algorithm efficient in practice.

Keywords
Single wagon load, train marshalling, optimization, PQ-tree

Session 2.4A: Timetabling II
Submission type: Industrial paper
Presentation type: Oral
Paper ID: [33]

Microscopic routing for mixed granularity routing requests

Alexander Kuckelberg

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For many tasks in the context of railway operations research analysis, railway operation and operational systems, microscopic train paths are essential and a basic requirement for reliable and meaningful findings and analyses. Such tasks are e.g. simulations of rail operation, detailed schedule planning in intensively used network areas, long and medium-term capacity planning, operational scheduling and more. The ability to create microscopic paths based on microscopic infrastructure data is clear, but in many cases the determination relies on incomplete, macroscopic data. This paper describes the implementation of a routing approach to determine microscopic train paths from requests of coarser granularity. Such inquiries can, for example, only include source and destination regions, but (partially) also be supplemented with information on desired routes, platform tracks, desired courses or line tracks. Various requirements are therefore placed on a flexible, high-performance routing algorithm for path search: interpolation between macroscopically defined support points, weighting of microscopic route priorities, suitability of stopping places, availability of train control systems, power systems, track gauges, but also following exact specifications and request data This paper derives a corresponding algorithm from the general Dijkstra approach, describes microscopic data and the path search based on it. In addition, the handling of requests of different granularity is described and optimization approaches are outlined. The paper concludes with an evaluation of the presented algorithm and its suitability in practice from a functional and technical perspective and the implementation in concrete products.

Keywords
microscopic routing, macroscopic path request, optimization, services

Session 3.3A: Timetabling V
Submission type: Industrial paper
Presentation type: Oral
Paper ID: [35]

Evaluation of Delay Reduction Measures based on Visualization of Historical Train Traffic Records and Data-Driven Simulation

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[b] *Nihon University*

In urban railway lines where trains are running very densely, small delays were quite often occurring during morning peak hours. Thus, railway companies were making a lot of efforts to reduce such delays. During the prevalence of COVID-19, however, such delays have been decreasing because the volume of passengers has decreased and this means the cause of delays is congestion. It is expected that the volume of passengers will increase gradually but the volume of passengers will not resume to the original. Hence, railway companies have to make a decision about what kind of delay reduction measures they should take considering the volume of passengers in the near future. In order to help the decision making process of railway companies, we propose an approach which consists of two steps. The first step is an analysis to find the bottleneck of timetable stability by appropriate visualization of historical train traffic records. The second step is a macroscopic simulator which is used to quantitatively evaluate delay reduction measures. We call the simulator Data-Driven simulator, because in this simulator, the three major factors, running times, headway times, dwell times are calculated from the historical train traffic records. Running times and headway times are decided considering the situation of trains and dwell times are calculated considering the volume of passengers. Thus, although the simulator is macroscopic, the accuracy is enough for our purpose. We have applied this approach to an actual railway line in Tokyo and proved our approach worked successfully.

Keywords
delay, simulator, visualization, historical train traffic records, COVID-19

Session 3.1A: Railway capacity II
Submission type: Research paper
Presentation type: Oral
Paper ID: [36]

A multi-objective framework for strategic railway timetabling: integration of ant colony optimization and mixed integer linear programming

Nicola Coviello[a], Giorgio Medeossi[a], Thomas Nygreen[b], Paola Pellegrini[c] and Joaquin Rodriguez[c].

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[b] *The Norwegian Railway Directorate*
[c] *COSYS-ESTAS, Univ. Gustave Eiffel, IFSTTAR*

This paper presents an algorithmic framework to perform automatic timetabling, developed within the project "Tools for mathematical optimization of strategic railway timetable models" funded by the Norwegian Railway Directorate (Jernbanedirektoratet). This project aimed at prototyping a tool to automatically generate timetable drafts, to help planners to perform such tasks as capacity studies and timetable planning. The paper describes the algorithmic core of the tool, called Automatic Timetabler with Multiple Objectives. The framework integrates a Multi-Objective Ant Colony Optimisation (MOACO) algorithm and a Mixed Integer Linear Programming (MILP) formulation. MOACO performs a fast-but-coarse exploration of the solution space, populating and maintaining at the same time a POS of timetables. The timetables generated by MOACO are refined by the MILP formulation, exploring a neighborhood of the input solution and returning feasible, high-quality timetables. The tool is assessed by a series of application tests, based on case studies driven from real practice in Norway.

Keywords
Ant Colony Optimization, MILP, Multi Objective, Train Timetabling Problem

Session 2.4B: Driver Advisory Systems and ATO
Submission type: Research paper
Presentation type: Oral
Paper ID: [37]

Energy-efficient High-speed Train Driving Considering Neutral Zone and Time window

Peiran Ying[a], Xiaoqing Zeng[a], Andrea D'Ariano[b], Dario Pacciarelli[b], Haifeng Song[c] and Tuo Shen[d].

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[c] *Beihang University*
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Among the many challenges which must be faced during the daily operation of high-speed rail, the management of the neutral zones in the catenary during unexpected disturbances remains underinvestigated. This study proposes an energy-efficient Intelligent Transportation System for Automatic Train Operation of a high-speed train with regenerative braking for passing neutral zones under disturbance. For the first time, different mechanism-based automatic passing neutral zone systems are analysed and modelled as location-based and time-based constraints, respectively. The disturbance is described as a nonuniform time distribution by time windows. The original model with location-based constraints is a nonlinear model that is transcribed as a quadratically constrained linear model and then solved. The optimality consistency and its establishment condition between the original and transcribed models are analysed based on the Karush-Kuhn-Tucker conditions. The model with time-based constraints is novelly transformed into an optimal coasting point problem. A high-quality solution is obtained effectively and efficiently by iteratively solving a series of subproblems. Comprehensive experiments are conducted based on practical data from a high-speed rail system in China. The benefit of the proposed method is significant compared to Mixed Integer Linear Programming and Artificial Driving Algorithms. Moreover, the impacts of different mechanism-based automatic passing neutral zone systems and a combination of time window settings are analysed in depth.

Keywords
High-speed rail, Energy-efficient driving, Intelligent transport systems, Time window, Neutral zone

Session 1.2B: Railway safety analysis and risk assessment
Submission type: Research paper
Presentation type: Oral
Paper ID: [38]

Towards Safe Machine Learning Driven Railway Infrastructure Monitoring Systems

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Control command and signalling (CCS) systems for railway operations are an active research area for potential machine learning (ML) applications. One such application is the train integrity and track occupancy detection fiber optic sensing system (FOS-System). As the ML models used in such applications are applied in safety-critical railway infrastructure systems to control safety-relevant system functions, they should be trustworthy and, more importantly, safe. However, due to their opaque decision-making processes, ML-based systems are challenging to prove safe according to existing methods (such as the CENELEC standards). To address this limitation, this paper derives relevant measures to apply ML models in safety-critical railway infrastructure systems, considering the use-case track occupation detection. First, it performs a risk analysis at the railway system level taking into account the system definition and the defined requirements for the FOS-System. Second, a Failure Mode and Effects Analysis (FMEA) on the system level based on the first step lists potential hazards. A heuristic method generates a list of failures of the FOS-System component, focusing on potential ML-based failures in the training and inference phase that may cause hazards. The paper then proposes appropriate measures to eliminate the mentioned hazards to a harmless level based on the FMEA. Finally, it proposes a Context-Aware Safety Envelope Monitoring Subsystem and performs a plausibility check considering the context while monitoring the safety envelope. Our proposed safety envelope employs physics-based rules and, is, therefore, deterministic – it can be validated with established norms, such as EN 50126 or 50128.

Keywords
ML-based systems, CCS, Safety-critical railway infrastructure, Fiber optic sensing system

Session 1.1A: Timetabling I
Submission type: Research paper
Presentation type: Oral
Paper ID: [39]

Train dwell time analysis for urban rail transit stations based on random forest algorithm: A case study on Beidajie station of Xi'an Metro

Wenyu Wang, Fangsheng Wang, Feng Zhou, Ling Hong and Ruihua Xu.

College of Transportation Engineering, Tongji University

Dwell time (DT) is an essential element in the compilation of urban rail transit train diagrams. To improve the reliability of urban rail transit operations, it is necessary to identify the major factors that influence the actual DT and formulate effective measures. Via data mining, this study proposes a random forest (RF) based identification model to diagnose the major factors that affect the DT at different stations in different periods, and put forward corresponding targeted measures. Considering the Beidajie (BDJ) station of Xi'an Metro in the upstream direction of Line 2, this model sensitively identifies major factors leading to the variation in DT during the morning peak, consistent with the detailed analysis. Then the targeted improvement measures are proposed for the BDJ station. The obtained application results indicate that the established influencing factor identification model can effectively distinguish the factors causing discrepancy between actual and scheduled DT, which can provide auxiliary decision-making in the compilation of train diagrams and daily operation organization.

Keywords
Urban rail transit, Dwell time, Random forest, Feature extraction

Session 3.1C: Rail freight transport III
Submission type: Research paper
Presentation type: Oral
Paper ID: [40]

Prediction of the Freight Train Energy Consumption with the Time Series Models

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Univerzitet u Beogradu Saobraćajni fakultet

The global energy crisis makes large problems and challenges for companies when planning transportation activity costs. Companies must carefully take care of energy spending and consider the ways how it can be decreased. In this paper, we considered the problem of predicting freight train energy consumption. For that purpose, we applied three-time series methods: the moving average, the weighted moving average, and the exponential smoothing method. These methods were applied to real data collected in the Republic of Serbia. The obtained results showed that the exponential smoothing method makes better results than the other two approaches. Nevertheless, there is still room for improvements in the presented approaches, making some fine-tuning of the used parameters and comparing to other relevant techniques used for forecast.

Keywords
Freight train, Energy consumption, Time series models

Session 3.3B: Train delay prediction and conflict detection
Submission type: Research paper
Presentation type: Oral
Paper ID: [41]

Applying Generative Adversarial Networks to Generate Synthetic Train Trip Data for Train Delay Predictions

Florian Hauck, Albrecht Güth, Natalia Kliewer and David Rößler.

Freie Universität Berlin

This paper examines the possibilities of creating synthetic train trip data with Generative Adversarial Networks (GANs). A real data set from Deutsche Bahn is enhanced with synthetic data created by using a Conditional Wasserstein Generative Adversarial Network (CWGAN). The synthetic data is analyzed and compared with the original data using statistical methods as well as machine learning models. The results show that the synthetic data is very similar to the original data in terms of data structure and dependencies, but at the same time contains enough noise to not just copy already existing instances. To analyze and measure the quality of the synthetic data, different supervised machine learning models are trained to predict the change of delay of trains at a specific station based on the arrival delays of other trains at that station. These models are then each trained once using the real data and once using the real data enhanced by synthetic data. All models are evaluated using a test set containing only real data that was not used to train the models. The results show that the r squared value of delay predictions increases significantly when using the enhanced data set. In particular, neural network based models can benefit from the larger amount of input data. The proposed approach of generating synthetic train trip data with a CWGAN can also be applied to a variety of other railway data analysis projects that require a large amount of input data. In addition, the presented approach is particularly interesting because, unlike most GAN approaches discussed in current literature, the data basis contains numerical data and not image data.

Keywords
Generative Adversarial Networks, Train Delay Prediction, Railway Analysis

Session 2.2C: Rail yard operation and design
Submission type: Research paper
Presentation type: Oral
Paper ID: [42]

The shunting with service scheduling problem at a Chinese high-speed railway depot

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A high-speed railway depot in China is the place where Electrical Multiple Units (EMUs) undergo services like repairing, cleaning, sewage suction and wheel repairing. The fast-growing number of EMUs in China poses a great challenge to the shunting with service scheduling (SSS) planning at the depot. The capacity of an EMU depot and the quality of the SSS plan can be improved by a shunting strategy that allows flexible storages and train relocation. This paper considers an SSS problem of integrating train shunting, service scheduling and routing at EMU depots with various layouts. Different from the Train Unit Shunting problem, EMUs in China are usually not decoupled and coupled, and thus the train unit matching is not included in this paper. As the SSS plan is currently handled manually by dispatchers, this paper constructs a two-layer time-space network and proposes a multi-commodity flow model for the SSS problem, which aims to minimize the total cost of all EMUs during the planning horizon. A heuristic algorithm based on the alternating direction method of multipliers (ADMM) is designed to decompose the original problem into independent EMU subproblems and improve the solution efficiency. The results of the real-word case study shows that the ADMM algorithm can yield a near-optimal (gap=5.7%) SSS plan in 1 hour computation time for depots of different layout types, and can be integrated in a computer-aided planning system.

Keywords
Train Unit Shunting, Service scheduling, Maintenance, Time-space network, ADMM

Session 2.5B: Digital Automated Train Operation
Submission type: Research paper
Presentation type: Oral
Paper ID: [43]

Virtual Validation Method of Automated On-Sight Driving Systems for Shunting Operations

Steffen Schäfer, Lucas Greiner-Fuchs, Tobias Hofmeier, Philipp Koch and Martin Cichon.

Technische Hochschule Nürnberg Georg Simon Ohm

Virtual scenario-based testing is considered best practice in the development and validation of highly automated driving functions. A scenario describes a holistic and coherent test setup in a use-case oriented environment in order to make a claim about the validity of derived test results. Railway kinematics are characterized by the system immanent track guiding allowing narrow clearance to infrastructure. High masses and low coefficients of adhesion result in long stopping distances. In addition, shunting is performed on sight whereas train line operation is performed on signaling. Ensuring a sufficient safety distance to obstacles, high sensor performances in range and resolution is required for real-time sensor-based object detection. A stable object classification and subsequent obstacle warning is mandatory for trouble-free automatic train operation (ATO). To validate the perception-based decision making, the following target braking or acceleration, the driver model and actuation systems, a huge number of situations has to be considered. Regarding time, cost and feasibility, real world operation cannot provide a complete set of necessary tests, thus, virtual scenario-based testing, also used for validation of advanced driver assistance systems in automotive engineering, is adapted. Therefore, a photorealistic railway environment designed along physical properties is developed. According to the layout and design of the system under test (SUT), the physical sensor positions and characteristics are simulated. Raw sensor data is emulated and looped out to the SUT respectively, where the driving decision is made. The decisions are wrapped and looped back to the vehicle model, an integrated module as a part of the simulation environment. Scheduled scenario setups including static and dynamic elements as well as expected system behaviors are defined as concrete test cases.

Keywords
Virtual testing, simulated sensor, validation, ATO, digital engineering

Session 2.2C: Rail yard operation and design
Submission type: Research paper
Presentation type: Oral
Paper ID: [44]

Predicting and Measuring Service Disruption Recovery Time in Railway Gravity Hump Classification Yards

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University of Texas at Austin

Planned maintenance and unplanned incidents cause service disruptions in freight railway classification yards that create congestion, delay railcars and may even impact mainline operations. Understanding the lingering performance impacts and recovery time of yard disruptions of various duration is vital for the industry to plan operating responses to disruptions, promote efficient resource utilization, and improve railway yard and network resiliency to unplanned events. This paper compares two major types of yard disruptions (temporary closure of the hump process, and temporary closure of the pulldown process) and quantifies the recovery pattern of yard processes as measured by different performance metrics. The authors propose an analytical approach for estimating the classification yard disruption recovery time as a function of the disruption duration and the baseline yard capacity utilization. To validate the hypothetical approach, a series of experiments were conducted to simulate a wide range of disruption duration and throughput volume using a representative hump classification yard model constructed in AnyLogic. The results indicate that recovery time is proportional to the shutdown duration with an approximately constant recovery rate, and recovery rate increases approximately exponentially with throughput volume. These results are consistent with the hypothesized analytical relationships, suggesting that this approach may also provide estimates of yard capacity using the disruption recovery rate under a baseline traffic volume. The methodology discussed in this paper also provides a foundation to study the interaction between railway classification yards and mainlines, and to construct planning-level parametric models of classification yard capacity and performance.

Keywords
Freight, Microscopic simulation, Disruption recovery, Capacity, Resiliency

Session 2.4C: Rail freight transport II
Submission type: Research paper
Presentation type: Oral
Paper ID: [45]

Multi-objective Express Shipment Service Network Design for High-speed Railway Networks

Siqiao Li, Xiaoning Zhu, Pan Shang and Li Wang.

Beijing Jiaotong University

The rapid growth of e-commerce and online sales have increased the pressure on express systems, and thus, a reliable and efficient express service is required. To deal with these problems, this study focuses on the express shipment service network design problem for a scheduled high-speed railway system. Different organization modes are introduced to form a capacitated service network, and a space–time network is constructed to facilitate the flow of shipments. To understand the trade-offs between service-centric and operator-centric perspectives, the problem is formulated as a multi-objective model considering the costs of passengers, shipments, and operators. The ε-constraint method is introduced to address the complexity of the problem. An adaptive update method is proposed to narrow the bounds given by the payoff table, after which the three-dimensional Pareto frontier is explored to highlight the relations between different objectives. Standardized Euclidean distance is introduced to evaluate the Pareto optimal solutions. The methodology is applied to a real-world high-speed railway network containing six lines to demonstrate its efficiency.

Keywords
High-speed railway, Express service, Multi-objective optimization, Pareto frontier

Session 2.5A: Timetabling III
Submission type: Research paper
Presentation type: Oral
Paper ID: [46]

Analyzing the impact of integrated train path selection and rolling stock planning in railway freight transportation

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This paper investigates how much gain is brought by the integrated planning of freight rail operations, in particular the selection of the railway infrastructure (train paths) and of the rolling stock (engines), compared to a classical sequential planning process. We propose various diversification methods, applied in an iterative approach, to analyze how different optimal or very good solutions for train path selection can lead to different rolling stock plans. The best resulting global solution is then compared to the worst global solution to evaluate the largest potential gain. Computational experiments on industrial data from SNCF, the French public railway company, are discussed. They show that interesting gains can be obtained, and motivate the development of solutions approaches to solve the integrated problem.

Keywords
Freight, Train path, Rolling staock planning, Railway transportation, Integrated planning, Mixed integer linear programming

Session 1.3A: Railway capacity I
Submission type: Research paper
Presentation type: Oral
Paper ID: [47]

Demand-based Capacity Assessment using Mixed Integer Programming

Christopher Szymula, Nikola Besinovic and Karl Nachtigall.

Technische Universität Dresden

Understanding railway network capacity and potential reserves proves crucial for optimal planning decisions, which are required due to the high utilization of European railway networks and the intended future modal shift of to rail. Capacity reserves emerge where the network structure does not match the demand. We propose a mixed integer program based railway network utilization model (MIP-RNUM) for investigating the capacity reserves in the network. Inspired by Petri Nets, this model allows to optimize the train ordering and the distribution of trains in the network, whilst regarding for the traffic demand to be served. The infrastructure is mesoscopically modelled by the individual blocks of the railway system. The demand is represented by a corresponding line plan and its given frequencies. The model determines the interrelations of demand and network capacity and thus allows to in- vestigate between transport demand and network infrastructure. We test the proposed model on different academic networks and a case study. In particular, the results show clear capacity effects of mismatched infrastructural demand and supply. It is thereby shown, that the efficient use of network capacity depends on the fit between demand and network structure. Furthermore, we can see that the emergent utilization behaviour is network specific and often non-linear, which strengthens the necessity of network approaches for global capacity assessment. Also providing support to other fields such as urban planning, the models incorporation to integrated and interdisciplinary planning approaches is left for future research.

Keywords
railway networks, capacity assessment, MIP, traffic demand

Session 3.2A: Timetabling IV
Submission type: Research paper
Presentation type: Oral
Paper ID: [48]

Timetable Optimization for Sharing-Corridor Metro Lines under Virtual Coupling

Jianhao Ge, Pengling Wang and Xiaofang Xiao.

Tongji University

This paper proposes a method to apply virtual coupling technology to the sharing-corridor metro lines to solve the problem of capacity bottleneck. A mixed integer linear programming model is built to optimize the train timetable of sharing-corridor lines under the assumption of using the virtual coupling technology, fully taking into account the constraints related to train timetabling, virtual coupling technology, and passenger assignment, with the objective to improve the service quality. The model adopts the departure times, arrival times and whether each train service is planned to be virtual coupled with its adjacent front one or the following one, as decision variables. A method is also proposed to evaluate the capacity utilization using virtual coupling technology referring to UIC 406. The experiments on Shanghai Metro Line 3 and Line 4 are implemented to verify the effectiveness on transport capacity and passenger service quality of the proposed model using virtual coupling technology. The results show that using virtual coupling technology can launch 8 more train services during morning peak hours and at most reduce passengers' waiting time by 73.8 seconds.

Keywords
Metro timetable optimization, Virtual coupling, Mixed integer linear programming, Capacity analysis

Session 2.2A: Disruption management
Submission type: Research paper
Presentation type: Oral
Paper ID: [49]

Dynamic constraint and objective generation approach for real-time train rescheduling model under human-computer interaction

Kai Liu[a], Jianrui Miao[b], Zhengwen Liao[b], Xiaojie Luan[b] and Lingyun Meng[a].

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Real-time train rescheduling plays an important role in railway transportation, which is critical for the punctuality and reliability of rail operations. In this paper, taking the actual situation as the premise, we propose constraint and objective generation of the rescheduling model by human-computer interaction, so that the model can meet the practical needs and daily tasks and reschedule trains through multi-iterations. The dispatcher's empirical knowledge is incorporated into the train rescheduling process through the human-computer interaction framework. Based on observations and analysis of the dispatcher's actual rescheduling process, we propose six interfaces and dynamically build the constraints and objectives to represent human intentions. Through the rescheduling rules summarized, we design rule-based conflicts detection-resolution heuristic algorithm to solve the defined model. We present a set of numerical experiments to demonstrate the system-wide performance benefits of the iterative framework, could make the rescheduling more flexible through secondary solving according to analysis to the last solution by the human-computer interaction. The proposed interaction method complements the existing literatures of rescheduling methods under human-computer interactions. It can assist dispatchers to find more feasible solution according with their empirical rescheduling strategies.

Keywords
Real-time train rescheduling, Human-computer interaction, Rule based heuristic, Secondary rescheduling

Session 2.2A: Disruption management
Submission type: Research paper
Presentation type: Oral
Paper ID: [51]

A MILP Model for Rescheduling Freight Trains under an Unexpected Marshalling-Yard Closure

Liyun Yu, Carl Henrik Häll, Anders Peterson and Christiane Schmidt.

Linköping University

This study is about rescheduling freight trains to reduce the effects of major interruptions. In this paper, we consider that the interruption is an unexpected marshalling-yard closure. We develop a macroscopic Mixed-Integer Linear Programming (MILP) model to reschedule railway timetables. One important principle is that we simultaneously reschedule several trains, instead of one-by-one. Furthermore, we consider a rescheduling strategy of letting trains wait on the way when the destination yard have a closure. The model considers stopping restrictions and the capacity of each segment and station. The order of the trains affected by the interruption is not fixed. We present experimental results of three different cases, which are all based on artificial data.

Keywords
Railway timetable rescheduling, Major interruption, Mixed-integer linear programming

Session 2.1A: Railway performance II
Submission type: Research paper
Presentation type: Oral
Paper ID: [52]

Weather-Related Railway Infrastructure Failures in Sweden: An Exploratory Study

Michelle Ochsner, Daria Ivina and Carl-William Palmqvist.

Lund University

The impacts of adverse weather conditions on railway infrastructure can result in delays and cancellations across the railway network and increased maintenance costs. The frequency and severity of extreme weather events are expected to rise due to climate change, making railways more vulnerable. This study aims to gain a better understanding of weather-related infrastructure failures (specifically track, catenary line, signal, and switch failures) between 2015-2020. We do so by using infrastructure failure data from the Swedish infrastructure manager, the Swedish Transport Administration. We use an exploratory data analysis approach to understand which infrastructure assets are most vulnerable to what weather-related phenomena and if infrastructure failures follow any seasonal trends. Results indicate that tracks and catenary lines are most vulnerable to fallen trees, likely linked to windy conditions, while switches are most vulnerable to snow and ice, and signals are most vulnerable to both snow or ice conditions and fallen trees. Additionally, most failures occur during the winter months. These results highlight the importance of increasing the resiliency of railways to extreme weather today and in the future.

Keywords
Extreme weather, Railway infrastructure failures, Vulnerability, Resilience, Adaptation

Session 1.1C: Passenger assignment
Submission type: Research paper
Presentation type: Oral
Paper ID: [53]

A passenger-oriented optimization approach for scheduling additional high speed trains with flexible stopping

Tianyin Zhao[a], Yongxiang Zhang[a], Qiyuan Peng[a], Qingwei Zhong[b], Shan Jiang[a] and Siyu Zhang[a].

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Every quarter, China State Railway Group Co., Ltd. (CR) adjusts the national train timetable for the sake of better adapting to market demand. CR routinely fine-tunes the train timetables by scheduling additional trains, and this strategy can significantly reduce the costs associated with timetable adjustments. This article studies the problem of scheduling additional trains with flexible stopping (SATFS) by using the space-time network modeling method. A new integer linear programming (ILP) model with multiple objectives is proposed for scheduling additional trains. With the goal of minimizing the weighted sum of running costs, adjustment costs, operation costs of trains, and passenger costs, the model enables trains to choose or alter their stop patterns flexibly and realize the joint optimization of scheduling additional trains and satisfying the passenger demand. The model incorporates accessibility constraints, which eliminates any inconvenience to passengers caused by the flexible modification of stop patterns. The Gurobi solver is called to solve the proposed ILP model, where the key coefficients are obtained by a series of experiments on a small-scale example. Moreover, a sensitivity analysis of three crucial parameters is performed. Finally, numerical experiments are conducted based on medium-scale examples to validate the viability of the developed model. The experimental results demonstrate that the revised train timetable obtained by the proposed model can effectively meet passenger demand through the scheduling additional trains.

Keywords
Scheduling of additional trains, Stop patterns, Integrated optimization, Passenger demand, Space-time network

Session 2.5A: Timetabling III
Submission type: Research paper
Presentation type: Oral
Paper ID: [54]

Considering Dispatcher's Intention in Real-time Train Rescheduling Problem Under a Human-Computer Interaction Framework

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During railway operations, trains normally run as scheduled, but the occurrence of unexpected events will disrupt traffic flow and cause train deviation from the original timetable. Currently the timetable rescheduling task is mainly conducted by train dispatchers based on their experience and intuition, but the massive computational effort imposes great physical and mental burden on them, especially in the high-density railway network. Furthermore, when train dispatchers are adjusting the scheduled timetable, they might make mistakes, which could affect train operation safety. In order to assist dispatchers, in recent years many optimization-based models are proposed. However, due to the large problem scale and dynamic optimization objective, in most cases these models cannot provide satisfactory results by themselves. With this motivation, this paper introduces an innovative Human-Computer Interaction framework into the timetable rescheduling process, aimed at integrating human and machine together. It enables train dispatchers to propose timetable adjustment instructions to the original or model-computed timetable. These instructions will be processed, stored, analyzed, and digested by computer program, which finally leads to the modification and/or calculation of model, then a new disposition timetable will be produced and provided to dispatchers for checking and modifying. This framework can iterate for unlimited times based on dispatchers' intentions, until the final result satisfies them. In order to show the effectiveness of our framework, we develop a demonstration system named RTARS (Real-time Timetable Automatic Rescheduling System), and a part of Beijing-Shanghai high-speed railway line is chosen as the test bed.

Keywords
Railway Transportation, Timetable Rescheduling, Human-Computer Traffic Management System

Session 2.1C: Line planning
Submission type: Research paper
Presentation type: Oral
Paper ID: [55]

Optimizing incomplete cyclic line plan in a rail network

Hailin Li, Lei Nie, Huiling Fu, Feng Gao and Huaibin Hu.

Beijing Jiaotong University

The line plan and train timetable are fundamental for passenger railway operation, which have two patterns: cyclic and acyclic. For rail network, the acyclic pattern may not well attract passengers because of the low service frequency and poor regularity. Whereas the fully cyclic pattern reduces the accessibility of direct service due to limited number of train ODs and stops. We define a line plan pattern that is dominated by cyclic nature and supplemented by acyclic nature as incomplete cyclicity. An integer nonlinear programming model is proposed to optimize the incomplete cyclic line plan (ICLP) with direct and transfer service frequency for passengers simultaneously determined, such that benefits of the two patterns are integrated. The effectiveness of our proposed method is tested on a real rail network with three high-speed rail lines interconnected in China. The results of case study show that the ICLP, which consists of 78% of cyclic trains and 22% of acyclic trains, performs improved regularity and higher service frequency than the practical acyclic one.

Keywords
Rail network, incomplete cyclicity, line planning, integer programming model

Poster session
Submission type: Industrial paper
Presentation type: Poster
Paper ID: [56]

Towards Automated Railway Operations - TARO

Bertram Ludwig and Philipp Kastberger.

ÖBB Holding AG

This paper outlines the goals as well as the status of project TARO (Towards Automated Railway Operations), a cooperative technology initiative led by the Austrian Federal Railways (ÖBB). Increasing the railways share in transportation is a key factor in reducing carbon emissions, but requires innovative approaches to increase capacity, quality and productivity. This includes automation and digitalisation of infrastructure and vehicles. TARO focusses on three primary research areas: Digital Twin (Work package 1: Digital Twin Vehicle, Work package 2: Digital Twin Infrastructure), Processes (Work package 3: Automatic Dispatching, Work Package 4: Future Shunting, Work package 5: Digital Automatic Coupling) and Automated Train Operation (Work package 6: Future regional rail). The three areas function as separate, but interconnected subprojects. This paper displays three particularly advanced work packages: Digital Twin Vehicle, Digital Twin Infrastructure and Future Regional Rail.

Keywords
Condition Based Maintenance, Digital Twin Vehicle, Digital Twin Infrastructure, Regional Rail

Poster session
Submission type: Research paper
Presentation type: Poster
Paper ID: [57]

Potential of the long-distance railway transport routes in the post-pandemic period in Europe

Milan Dedík, Zdenka Bulková, Lumír Pečený and Martin Vojtek.

University of Žilina

Quality and attractive long-distance railway passenger transport should become a key element and system of public passenger transport which must be the basis for the national and international comprehensive integrated system of passenger transport. Due to several COVID-19 restrictions and measures the demand for public passenger transport has been significantly decreased since March 2020 in many European countries. The reduction in mobility has had an impact on passenger transport performance. The number of national rail passengers fell by as much as 90% during the first wave of the pandemic compared to the previous year. The second wave of the pandemic in autumn 2020 has forced many countries to take further restrictive measures regarding population mobility and subsequent cancelation of several connections. The paper deals with a brief analysis of traffic performance within individual European countries during the corona crisis. The main research part of the contribution is focused on current potential determination of the long-distance railway transport route. Subsequently a new concept of traffic potential determination in long-distance railway passenger transport is proposed. The paper contains practical application for indicators determination of selected long-distance transport routes including concrete examples and calculations.

Keywords
railway transport, long-distance routes, pandemic COVID-19, traffic potential, public passenger transport

Session 3.2A: Timetabling IV
Submission type: Research paper
Presentation type: Oral
Paper ID: [58]

Cross-line Train Service Planning considering Passenger Travel Demand after Large Events

Zhiwen Jiang, Yun Bai and Zongran Li.

BeijingJiaotong University

Urban rail transit is one of the most important ways to transport passengers after large-scale activities in mega cities. The large passenger demand caused by large-scale activities need to be transported from the station close to large event venue to their destination stations in the metro network. Trains acrossing different metro lines can effectively reduce passengers' transfer time. Besides, the cross-line operation can also reduce the enterprise operation cost by decreasing running kilometres of trains. This paper proposes an optimization model for the train cross-line operation plan. The objective is to minimize the passenger travel time, the number of stranded passengers and the enterprise operation cost. A genetic algorithm is designed to solve the model. Case studies show that compared with the separate-line operation plan, the cross-line operation plan can reduce the enterprise operation cost and the stranded passengers by 17.42% and 55.26% respectively.

Keywords
Urban rail transit, Large events, Cross-line operation, Train service planning

Poster session
Submission type: Research paper
Presentation type: Poster
Paper ID: [59]

Combined Lines-Nodes Capacity Assessment in Freight-Passengers Complex Railway Networks

Atieh Kianinejadoshah and Stefano Ricci.

Sapienza University of Rome

The framework is the increase of competitiveness of European transport industries based on the Technical Specification for Interoperability (TSI) with the purposes of a unique, harmonized and generally valid understanding on how to increase frequency, punctuality, speed and capacity. The work is specifically addressing the issues of the combined effect on lines operation of conflicts in stations and the propagation in stations of delays suffered along the lines. The paper proposes innovative solutions for the combined calculation of the capacity of the node-station complex systems, by applying analytical and simulation methods useful to rationalize the traffic and minimize the delay. The research starts from the application of the methods in a quantitative virtual test network including single and double track lines and three stations, in view of the applications to a complex case study, the Trieste railway node, situated in north-eastern Italy, including the passengers and freight stations and the lines operated for both services. Afterwards, the traffic simulation by a largely recognized software (Opentrack®) completed the study by allowing at comparative analyses for the validation and the finer tuning of the methodological approach.

Keywords
Railways, Capacity, Timetabling, Simulation, Signalling

Poster session
Submission type: Research paper
Presentation type: Poster
Paper ID: [60]

Railway Passenger Kilometers Forecasting with Combined Multi-Grey Neural Network Model

Yingsi Huang[a], Yuyan Tan[a], Yafeng Ma[b], Zizhen Zhao[a] and Yaxuan Li[a].

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[b] *East China Jiaotong University*

Accurate forecasting of railway passenger kilometers (RPK) plays an important role in railway passenger transport organization and resource allocation. Considering the railway passenger kilometers in China influenced by multiple factors, with unclear internal relationships, a forecasting method of combined multi-grey neural network model (G_GMBP), applying grey correlation is constructed. The traditional GM (1,1) model, unbiased GM (1,1) model and power function method improved unbiased GM (1,1) model are used for preliminary prediction. Then BP neural network is used to optimize the combination of the three previous prediction results. Meanwhile, the main influence index of railway passenger kilometers extracted by grey correlation analysis is added as another part of the input of BP neural network. According to the error back propagation, the combined weights are adjusted to obtain the better weight coefficients and fully fit the data characteristics. Numerical experiments based on the real data of railway passenger kilometers in China, during 2000-2019, are carried out to verify the effectiveness of the proposed model. The empirical results demonstrate that the prediction effect of the G_GMBP model is obviously better than the comparative prediction method, and significantly improve the accuracy of RPK prediction.

Keywords
Railway passenger kilometers forecasting, Combined model, BP neural network, Grey model, Grey correlation analysis

Session 2.1C: Line planning
Submission type: Research paper
Presentation type: Oral
Paper ID: [61]

Optimization of Periodic Train Timetable Considering Adding and Reducing Train Stops

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Due to the regularity of stops, the balance of services and the convenience of transfers, periodic train timetable is widely used in many countries, which provides reference cases for the adoption of periodic timetable in China. However, it can be seen from the practical experience that the stop plan of timetable of China's high-speed railway is not regular and reasonable enough. On the one hand, the train timetable with irregular train stops cannot properly serve the diversified passenger flow of different levels; on the other hand, the redundant train stops increase the train travel time. So, it is necessary to adjust train stops while optimizing periodic train timetable. This paper focuses on stop planning in the periodic timetabling process. Based on the periodic event scheduling problem model, a periodic train timetable optimization model is proposed with consideration of adding and reducing train stops. The train stop variables are introduced to realize the stopping flexibility. The optimization objective of the model is to minimize total train travel time. The flexible stop constraint and OD service constraint are included to meet the diverse passenger demand. The model is applied to the Chinese Jinan-Qingdao High-speed Railway Corridor and the result validates the correction of the model, which is an exploration of the possibility of adopting periodic train timetable in China.

Keywords
Periodic timetabling, PESP, Train stop, High-speed railway

Session 1.2A: Railway performance I
Submission type: Research paper
Presentation type: Oral
Paper ID: [62]

On the Fragility of a Train Timetable

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[b] *SINTEF*

In dense railway traffic, the delay of a single train may propagate in a domino effect over the network, causing a sequence of knock-on delays. During the last decades, several approaches have been proposed to measure and reduce these effects. These approaches are typically related to a particular definition of timetable robustness, however, they may not accurately predict knock-on delays, which can be significantly reduced by effective real-time dispatching. As a result, existing robustness measures are not always relevant to route planners for understanding how to increase the robustness of a timetable, and they may be of little interest to real-time dispatchers. In this work, we introduce the concept of timetable fragility as complementary to that of robustness, in order to identify the critical sections of a timetable, where primary delays are more likely to cause major knock-on delays, as well as the corresponding interconnections between trains and infrastructure. According to this concept, a section of a timetable is more fragile than another one if primary delays on this section will propagate more easily, even after the best possible real-time dispatching. To compute the fragility, we propose a MILP model where the minimization of the delay propagation is a key performance indicator. We show how the timetable fragility can be efficiently computed for optimal real-time train scheduling but also exploited by route planners at operational level. We test our approach on real-life scenarios from a busy railway line in Norway.

Keywords
Mixed-Integer Programming, Train Scheduling, Timetable Robustness

Session 2.2A: Disruption management
Submission type: Research paper
Presentation type: Oral
Paper ID: [63]

Application of reversible tracks in real-time train rescheduling during partial blockages

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[b] *KU Leuven*

Reducing the propagation of train delays is typically a crucial objective in real-time railway disruption management. This paper introduces the concept of reversible tracks to provide more options to temporarily keep blocked trains waiting in a station area. A mixed integer linear program is constructed to optimize the response to partial blockages, also using these reversible tracks. Its main idea is to effectively utilize the buffer time in the non-blocked direction to decrease the propagation of delays in the blocked direction. In order to validate the feasibility of our model and method, a part of the Beijing-Guangzhou high-speed railway is chosen as a case study. Considering the uncertainty of the blockage end time and the scale of the practical model, a rolling horizon algorithm and a series of methods to reduce the solution search space are proposed to improve the efficiency of the method and to meet the application requirements. The results show that the use of reversible tracks can reduce train delays by up to 18.95%. It proves that our method can reduce the accumulation of train delays and helps the blocked trains to recover as soon as possible.

Keywords
Disruption management, Mixed integer linear programming, High-speed railway, Rolling horizon, Reversible track

Session 3.3C: Railway traffic management and rescheduling II
Submission type: Research paper
Presentation type: Oral
Paper ID: [64]

A high-speed railway traffic control approach with local-rerouting and adaptive rescheduling range

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The Railway transport planning department ensures no conflicts in sections and stations by the timetable and the siding using plan. However, the plan is often interfered by various calamities. Then, it is necessary to adjust the timetable, e.g. arrival and departure times and siding use of some trains, to restore operation back to planned as soon as possible. To model the problem, we propose an event-decision network for train rescheduling, which is used to develop an integer programming model, considering five rescheduling strategies including changing train dwell times, changing train running times, adding extra stops, delaying the entering research area time, and changing local routes/siding-tracks. A heuristic algorithm based on Lagrangian relaxation is designed to solve the problem. For various disturbances scenarios, the heuristic algorithm can dynamically determine the range of trains which should be rescheduled. The model and algorithm are tested based on the actual operation data of Beijing Shanghai high-speed railway. The results show that the proposed method can quickly obtain a feasible solution under different speed limit interference scenarios.

Keywords
Train rescheduling, Event-decision network, Integer programming, Lagrangian relaxation, Adaptive rescheduling range

Session 3.2B: Passenger flows
Submission type: Industrial paper
Presentation type: Oral
Paper ID: [65]

An algorithm to estimate dwell time of trains based on association rules for real-time train traffic prediction

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As described herein, we propose an algorithm to estimate train dwell times based on association rules inferred from historical train traffic records. The algorithm is useful for real-time train traffic prediction. Passenger needs for detailed train traffic information have increased recently, not only for tactical timetables and train operations or suspensions but also for current trains' running positions and delays. Moreover, near-future predicted arrival and departure times become increasingly important because of the spread of route search services that incorporate train delays. Train delay causes are diverse, but dwell time in a station is a main reason for increased or decreased train delay. Consequently, estimating station dwell times while considering real-time train operations is useful. With such estimation capability, we can predict near-future arrival and departure times more precisely using accurately estimated dwell times. A control center operator would then be able to dispatch trains when delays occur. After the new algorithm receives classified dwell times of some recent stations as input data, it classifies dwell times of the succeeding stations in the near future as output data. Some results of application to actual data are presented herein to demonstrate our algorithm's effectiveness for estimating train dwell times.

Keywords
dwell time estimation, association rule, real-time train traffic prediction

Poster session
Submission type: Research paper
Presentation type: Poster
Paper ID: [66]

Dynamic Train Priority Rescheduling Model with Mixed Passenger and Freight Traffic using A Rolling Horizon Solution Approach

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This paper proposes a novel dynamic train priority rescheduling method to realize the train rescheduling with mixed passenger and freight traffic. The proposed method introduces the concept of dynamic priority into the train rescheduling. By taking the train type, train delay and remaining running time as the train priority characteristic parameters, the train priority can be determined dynamically according to the actual running state of the train. Compared with the static priority rescheduling method, the dynamic priority rescheduling method can better reflect the actual needs of train rescheduling. This paper constructs a mixed integer programming model with the goal of minimizing the weighted total event deviation time. A rolling horizon solution approach for dynamic train priority rescheduling model is designed, which can realize the dynamic train timetable adjustments. We demonstrate the proposed rescheduling approach for multi-type trains on the Lanzhou-Lianyungang railway, which is a conventional railway lines with mixed passenger and freight traffic in China. The results show that compared with static priority rescheduling, our method has a positive effect on reducing the loss of train delays when facing to disturbance occurrences, and it has important reference value for the train real-time rescheduling with mixed passenger and freight traffic.

Keywords
Railway with mixed passenger and freight traffic, Dynamic priority, Train rescheduling, Rolling horizon algorithm

Session 1.3A: Railway capacity I
Submission type: Research paper
Presentation type: Oral
Paper ID: [67]

Evaluating Timetables' Capacity Utilisation with An Extended Event-activity Network Method

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When scheduling a timetable for a busy network, it is very hard to ignore the routing problem because node stations might contain many conflicting train movements. Traditionally, timetable generation and routing problems are macroscopic and microscopic works, respectively. As a result, recurrent adjustments or challenging timetabling coordination among different parts of the network will lead to overall railway planning inefficiency. Therefore, an extended event-activity network (EEAN) model is designed to solve the integrated timetable generation and routing (ITGR) problem. The objective function is to minimise the timespan of a given train line plan, and the timespan is defined as capacity utilisation. A preferred-order heuristic algorithm is designed as a solution to the EEAN model. The study takes a Beijing-Shanghai-based network as the case scenario. The testing results show that the train order has a significant impact on capacity utilisation.

Keywords
Railway Capacity, Integrated Timetabling Problem, Event-activity Network, Mix-integer Programming

Session 1.1B: Emerging railway technologies
Submission type: Research paper
Presentation type: Oral
Paper ID: [68]

Challenges and opportunities for the railway system in 2050: results from a survey of experts

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The share of public transport in total traffic of the railway is relatively small, although the railway system has the properties of being very energy efficient, very space efficient and capable of delivering transport services of high quality (speed, comfort, etc.). The technological further developments enable further improvements in many areas. The aim of this study is identify challenges and opportunities for the technological further development of the railway system to ensure the expansion of railway services, and enabling a modal shift. For this, 30 experts from the areas of railway operator, industry and research from Switzerland and Europe were surveyed in multi-stage interviews concerning a holistic technological view on the system. The results are categorized in the areas supply, operational and technology and evaluated by their potential, system impact time horizon and model shift impact. The findings show, there is no single game changer in the system, but many aspects which contribute to the technologies further development. The largest developments are expected in the area of automation of the railway system. Revolutionary changes and completely new systems are perceived as unlikely, due to cost, benefits, and life cycle aspects which are very difficult to estimate.

Keywords
Future railway, technological development, pull measures, railway system 2050, experts survey

Session 1.3B: Train delay prediction
Submission type: Research paper
Presentation type: Oral
Paper ID: [69]

Examining the Validity of Using Train Position Data for Railway Traffic Control by Machine Learning

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University College London

Currently, railway traffic control at junctions, in particular during disruptions, is still mainly conducted by signallers. There have been studies that utilise optimization techniques and simulation models, but they need some time to produce solutions and simulation model development can be resource-consuming. This research investigated the validity of applying an offline reinforcement learning approach to berth-level log data of signal systems. It developed a Conservative Q Learning (CQL) framework to transform log data to training data, then applied it to a set of data of a case study area around London Waterloo East Station. We found that the RL model converged quickly with a total 8000 training steps and that obtained Q values were sound. This result suggests that the developed framework seems promising and can be researched further for railway traffic management.

Keywords
Signal data, Railway junction control, Reinforcement learning, Conservative Q Learning

Session 3.1A: Railway capacity II
Submission type: Research paper
Presentation type: Oral
Paper ID: [70]

Capacity gains with virtual sub-sections in the ETCS Signaling System

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Ramboll

This article describes the main differences between level 1-3 in the new European signaling standard, ETCS, and conventional signaling systems. Besides, the relatively new hybrid signaling system between ETCS level 2 and 3 – hybrid level 3 with virtual sub-sections – is described. Based on the description, the differences in headways and capacity between level 2, hybrid level 3 with virtual sub-sections and level 3 are investigated using a line headway calculation model. The results demonstrate ETCS level 3 have shorter headways than level 2 and hence higher capacity, and that hybrid level 3 with virtual sub-sections headways is between level 2 and 3. The exact capacity of hybrid level 3 with virtual sub-sections compared to level 2 and 3 depend on the length of the virtual sub-sections and the proportion of trains equipped with train integrity monitoring system. The article discusses on which types of railway lines ETCS level 2, hybrid level 3 with virtual sub-sections and level 3 are the most relevant. Besides, it is discussed that the capacity gain of higher levels of ETCS is the biggest for succeeding trains with the same speed and operational pattern.

Keywords
Railway capacity, Signaling, ERTMS, ETCS, Virtual sub-sections

Session 3.1C: Rail freight transport III
Submission type: Research paper
Presentation type: Oral
Paper ID: [71]

Optimizing Resource Planning in Shunting Yard with Constraint Programming

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The shunting yards are operated to disassemble and assemble rail cars, which is crucial for freight transportation in the railway network. The efficiency of shunting yards has a profound impact on railway freight service reliability. However, the utilization of resources often becomes the key to restricting the operation efficiency of shunting yards, which is also the main reason for the uncertainty of the yard processing time in addition to the complex organization process. To address this challenge, we introduce a hybrid flow shop scheduling problem (HFS) to find optimal schedules for the resource allocation in the yard. To solve, we develop a new constraint programming (CP) model. The performance of the proposed approach has been demonstrated in a Chinese shunting yard. Furthermore, we discuss the benefits of the proposed approach and future directions for extension under the framework of real-time yard resource scheduling.

Keywords
Shunting yard, Hybrid flow shop scheduling, Freight transportation, Constraint programming

Session 2.1C: Line planning
Submission type: Research paper
Presentation type: Oral
Paper ID: [72]

Optimization of the Combination of Cycle Times for High-Speed Railway Network

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Beijing Jiaotong University

Periodic operation mode has been given much attention to high-speed railway recently in China. The reasonable cycle time is the basis for both the periodic train line plans and cyclic train timetables. However, there is a lack of quantitative research on the length of cycle time. This paper presents a method to determine the periodic train ODs and construct the periodic line pool. Then, a bi-objective integer programming model is proposed to obtain the periodic line plans under different combination of cycle times, which comprehensively considers the number of direct ODs and the estimated transfer times. We use the corresponding periodic line plan as an evaluation tool to compare the pros and cons of different combinations in the network level. Computational experiments based on the real data of railway network composed of Beijing-Shanghai high-speed railway, Qingdao-Jinan high-speed railway and Xuzhou-Lanzhou high-speed railway are carried out and the results of eight cycle time combinations, of which each railway line has two options: 1h and 2h, are compared to demonstrate that the recommended combination is that the cycle time is set to 1h for all three railway lines in the experiments.

Keywords
High-speed railway, Cyclic operation mode, Periodic line plan, Cycle time, Bi-objective integer programming model

Session 3.1B: Rolling stock and crew scheduling II
Submission type: Research paper
Presentation type: Oral
Paper ID: [73]

Real-time train timetable and rolling stock circulation plan rescheduling in an urban rail transit network: an integrated optimization approach

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Real-time train rescheduling is necessarily required to deal with the disturbances that occur in the urban rail transit (URT) system, since the disturbances may cause delays and disturb the operations of the URT system. This paper studies the integrated rescheduling problem of the train timetable and rolling stock circulation plan in a URT network with a high train operating frequency. An integer linear programming (ILP) model is proposed, as the train timetable rescheduling (TTR) problem is modeled through an event-activity network, and the rolling stock rescheduling (RSR) problem is modeled as a multi-commodity flow problem. The objective of the model focuses on minimizing the weighted sum of the total economic penalties for service cancellation, delay, and deviation from headway. Meanwhile, rescheduling strategies, such as TTR, RSR, skipped stops, short-turning, and cancellation, are considered and integrated into the ILP model. To solve the large-scale rescheduling problem more efficiently, a time decomposition algorithm is developed to divide the whole problem into several subproblems and solve each subproblem sequentially with the Gurobi solver. The integrated model is tested on a set of real-world cases based on the 2022 INFORMS RAS problem solving competition, which verifies the effectiveness of the integrated optimization of TTR and RSR. The results show that the integrated model can effectively reduce the spread of delays in the URT network and restore the normal operations of train services.

Keywords
Integrated optimization, Train timetable rescheduling, Rolling stock rescheduling, Integer linear programming model

Session 1.1B: Emerging railway technologies
Submission type: Research paper
Presentation type: Oral
Paper ID: [76]

Optimizing rollout strategies for migration to moving block signaling – a MINLP-based approach for on-board train integrity monitoring technology

Jakob Geischberger, Alessa Isberner and Norman Weik.

German Aerospace Center, Institute of Transportation Systems

Increasing demand on heavily-used rail corridors in line with the modernization of the signaling architecture are key drivers for migrating to modern, moving-block based train control in the European railway network. In order to maximally profit from the increase of reliability and reduction of costs associated with shifting towards full ERTMS Level 3 from a network management perspective, additional requirements on the fleet management level arise. Amongst other things, all trains operating on these lines need to be equipped with on-board train integrity (OTI) monitoring solutions. In order to facilitate the planning of the OTI network migration processes, a MINLP-model is proposed which allows economic optimization of OTI migration in view of fleet allocation and the removal of trackside equipment for train integrity verification within the network. The model is tested in a case-study based on a generic network abstracted from the Austrian mainline network and found to significantly enhance planning compared to heuristic migration strategies.

Keywords
Railways, on-board train integrity, network migration, optimization

Session 2.5B: Digital Automated Train Operation
Submission type: Research paper
Presentation type: Oral
Paper ID: [77]

Embedded Model Predictive Train Control

Dimitris Kouzoupis[a], Ishan Pendharkar[a], Jonathan Frey[b], Moritz Diehl[b] and Francesco Corman[c].

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Train trajectory optimization for energy-efficient and minimum-time train control has attracted the attention of many researchers and practitioners, due to its potential in driver advisory systems and in automatic train operation. For algorithmic developments in the field to have an impact on the railway industry, it is evident that low computation times are of paramount importance. Various methods based on Pontryagin's maximum principle and dynamic programming have been proposed in the literature that satisfy this requirement, each with their advantages and limitations. In this paper, we use state-of-the-art methods and software from the field of embedded optimization to repeatedly solve trajectory optimization problems as the train progresses on the track. We demonstrate how challenging problem formulations can be tackled in milliseconds, even on resource-constrained hardware, and study the effect of feedback delay on the control performance.

Keywords
Energy-efficient train control, optimal control, multiple shooting, embedded optimization

Session 2.1B: Railway traffic management and rescheduling I
Submission type: Research paper
Presentation type: Oral
Paper ID: [78]

Designing self-organizing railway traffic management

Leo D'Amato[a], Federico Naldini[b], Valentina Tibaldo[a], Vito Trianni[a] and Paola Pellegrini[b].

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Railway traffic management requires a timely and accurate redefinition of routes and schedules in response to detected perturbations of the original timetable. To date, most of the (automated) solutions to this problem require a central authority to take decisions for all the trains in a given control area. An appealing alternative is to consider trains as intelligent agents able to self-organize and determine the best traffic management strategy without any central control. This could lead to more scalable and resilient management strategies, that can also take into account the real-time mobility demand. In this paper, we propose an implementation of a self-organizing railway traffic management system, designed in a way to enable real-world deployment. We describe the different processes brought forth by the trains in a decentralized way, and evaluate the approach in a realistic setting representing traffic in a French control area. The results confirm that self-organizing railway traffic management is a viable option, and foster further research in this direction.

Keywords
Railway traffic management, Optimization algorithms, Self-organization, Consensus

Session 2.1C: Line planning
Submission type: Research paper
Presentation type: Oral
Paper ID: [79]

Flexible trains in timetabled traffic

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RISE Research Institutes of Sweden AB

In Europe, trains run according to a timetable. Arrival and departure times at all stations are specified beforehand and should be adhered to during operations. However, some types of freight trains could benefit from more flexible operations that, e.g., allow trains to depart whenever they are ready. In this paper, we investigate the feasibility of operating trains with different types of flexibility on a line primarily used by freight trains. Two types of flexibility are employed depending on the type of traffic: departure flexibility and in-between delivery commitment flexibility. The former means that trains can run completely flexibly, while the second ensures that trains arrive and depart on time at commercially important locations. Iron ore trains could benefit from more flexible operations, and our case study is the Iron Ore Line in Sweden and Norway. Two types of analysis are used to evaluate whether more flexible operations is feasible. First of all, operational data is analysed to assess the flexibility of the current operation, i.e., to assess whether the established timetable is followed. Secondly, timetable analysis is used to assess the potential benefit of allowing flexible departures. The results show that the traffic is already operated quite flexibly, and that departure flexibility in combination with in-between delivery commitments flexibility seems to be both feasible and beneficial. In particular, a small degree of in-between delivery commitments flexibility improved the quality of the departure flexible train paths.

Keywords
Railway timetabling, flexibility, rail freight planning, structured traffic

Session 2.1B: Railway traffic management and rescheduling I
Submission type: Research paper
Presentation type: Oral
Paper ID: [80]

Railway Rescheduling Considering Rerouting of Connecting Trains after Perturbations

Bishal Sharma[a], Paola Pellegrini[a], Joaquin Rodriguez[a] and Neeraj Chaudhary[b].

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In busy networks, several connecting trains run throughout the day, and passengers often transfer from one train to another. To allow transfers, a minimum amount of time is allotted for connections, called minimum connection time. During operations, trains may get delayed when there is a perturbation in the network. Reducing the connection time between trains is one option to limit delay propagation but enough time must be left for passengers to transfer.
Real-time Railway Traffic Management Problem (rtRTMP) consists in adjusting train timetables in the presence of perturbations. It does so by employing appropriate control measures, such as re-timing, re-ordering, and re-routing. In this research, we extend an existing mixed-integer linear programming based algorithm for the rtRTMP. Specifically, we propose two enhancements to limit delay propagation by exploiting connection time buffers. We use a case study from the French Lille-Flandres station to validate the enhancements.

Keywords
Real-time traffic management, Rescheduling, Passenger connections, Train rerouting, Connection time

Session 2.2B: Railway alignment and network design
Submission type: Research paper
Presentation type: Oral
Paper ID: [81]

Line Edge Graphs: a Methodology to Model and Determine Generic Lines, Line Plans and Line Type Services in Public Transport Planning

Stefano Gioia

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In line planning, the direct connections constituting lines generally derive from predefined supply networks per linetype (or line type, each usually offering different speed and comfort levels to the passengers, e.g. Regional, Inter-Regional), or linetype networks, and available line plans for which different stopping patterns (possibilities) may be evaluated. Relevant connections according to typical operations research objectives, related to customers (depending on demand models, e.g. travel time) and operating costs, may be excluded. Instead, the connections could be selected before evaluating and for generating the line pool (candidate lines set), offering the possibility to define linetype networks even from scratch and to evaluate only effective stopping patterns. Moreover, lines are designed to serve all the stops (so connections) on the path specified in their linetype network or in the transportation network, if additional connections or stopping patterns (implying skipping stops) are not given. How to obtain line plans without these restrictions? How to determine the effective direct connections and (candidate) lines for a multi-linetype-based (multimodal) service? What is the impact of such service level or product differentiation? This work solves the outlined issues by introducing Line Edge Graphs, which can model all the possible candidate direct connections and any line expressed as sequence of them. It's also shown how the proposed methodology can consider multiple objectives as perceived travel times, operating costs, transfers, direct travelers. Reductions of 22% and 7% for costs and travel times can be reached concurrently for a regional line plan in Switzerland.

Keywords
Halting Patterns, Line Pooling, Demand Modeling, Multimodal Transportation Network Design, Applied Mathematics

Session 2.5C: Railway simulation and digital twins
Submission type: Research paper
Presentation type: Oral
Paper ID: [82]

Single track dispatching using Petri nets

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Simulation of railway operations are often an efficient way to analyse the complex system of the single-track line. We present a High-level Petri Net model capable to analyse concurrent behaviour of distributed systems and to model the railway operations on a single-track line with hierarchical structure of connected modules. One of the modules uses Petri Nets properties to incorporate dispatching logic as a set of controlling actions during the simulation run. Dispatching logical reasoning uses train location as an input, and comparing traffic situation, available tracks in neighbouring stations and train priority regulates train movements. We have tested the model on the on a section of a single-track railway line in Serbia, between Vrbas and Žednik. Simulation results provide details on typical details on trains movement (train times), and section occupation, but also provide results related to the activation of dispatching subsystem where three dispatching actions were observed: trains stopped on the main track, trains diverted to one of the sidings, and trains diverted to siding and stopped. In this paper we focus on results related to the actions triggered by the dispatching module and test three scenarios with different inputs.

Keywords
Deadlock prevention, High-level Petri nets, Railway simulation, Train dispatching logic

Session 1.1C: Passenger assignment
Submission type: Research paper
Presentation type: Oral
Paper ID: [84]

Information to passengers under overcrowding situations: good or not

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ETH Zurich

In public transport systems, vehicles can sometimes be so crowded that passengers experience onboard discomfort or are even denied boarding. The overcrowding situations can happen during peak hours of a day or during special events (e.g. music festivals and sports) that introduce huge travel demand for specific stations. Publishing the information about the overcrowded vehicles could benefit some passengers but at the same time negatively affect others. In this paper, we show the (dis)advantages of information provision to specific passengers during overcrowding, and investigate the conditions under which providing information is good or not from the perspective of the whole system. We develop different information provision strategies, which differ in the information content; and analyze the effects of these strategies considering the resulting delays over all passengers in our designed overcrowding scenarios. The results indicate that whether to give information and how much information should be given are relevant to the ratio between the benefiting demand and the negatively-affected demand, the proportions of passengers who can benefit from any information and the passengers who can only benefit from specific information, and the travel time differences between different alternatives. According to the results, we suggest that operators can play with the information to distribute the passenger flows towards a system-optimum condition that leads to the smallest passenger delays when vehicle capacities are in short supply.

Keywords
public transport, overcrowding, passengers, information

Session 1.2A: Railway performance I
Submission type: Research paper
Presentation type: Oral
Paper ID: [85]

Capacity Evaluation of ERTMS/ETCS Hybrid Level 3 using Simulation Methods

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ERTMS/ETCS Hybrid Level 3 was designed with the goals of achieving higher capacity and increasing the robustness of the railway network, in a cost-effective way. This paper evaluates the capacity effect of Hybrid Level 3 on both microscopic (two trains) and macroscopic (network) levels. Key performance indicators, headway for microscopic model, and punctuality and capacity utilization for macroscopic model are identified and used to evaluate the effects on capacity gains. Two microscopic cases have been conducted to look at how the performance indicator headway is affected by different lengths of virtual blocks. Using the microscopic mode in RailSys simulation software, the interaction between two trains has been studied. The results show that the headway is similar for different virtual block lengths. Furthermore, two macroscopic cases look at how the performance indicators punctuality and capacity utilization are affected by the share of Level 2 and Level 3 trains in a Hybrid Level 3 system. Simulations have been conducted in RailSys macroscopic mode, using a real-world infrastructure and a complete timetable. The result shows that the share of Level 2 and Level 3 trains has minor effect on punctuality and capacity utilization.

Keywords
ERTMS, ETCS, Hybrid Level 3, Virtual Sub-Section, Capacity

Session 1.1A: Timetabling I
Submission type: Research paper
Presentation type: Oral
Paper ID: [86]

Robust optimization of train timetable with short-turning strategy considering uncertain passenger demand and vehicle selection

Fangsheng Wang, Pengling Wang, Zixuan Zhu, Xiaofang Xiao and Ruihua Xu.

Tongji University

Considering the uncertainty of passenger demand and vehicle selection, this paper investigates a robust optimization approach for the train timetabling problem with short-turning strategy in urban rail transit system. With the scenario-based representation of passenger distribution, a mixed-integer linear programming (MILP) model is formulated that simultaneously integrates train timetabling, short-turning strategy and rolling stock circulation. The proportion of passengers who take the short-turning train services to the last station of the short-turning region and transfer to the full-length train services to their destination stations, is introduced to describe the passenger vehicle selection behavior under short-turning strategy. Finally, three experiments are designed for Xi'an Metro Line 3 to verify the solution quality and effectiveness of the proposed methods. The results indicate that the robust train timetable can more effectively satisfy multi-scenario passenger demand than the satisfactory train timetable generated by independent optimization of each demand scenario.

Keywords
train timetable, robust optimization, short-turning strategy, uncertain passenger demand, vehicle selection

Session 1.2A: Railway performance I
Submission type: Research paper
Presentation type: Oral
Paper ID: [88]

Increasing Robustness at Single-Track Lines using the Indicator Robustness in Passing Points

Emma Solinen and Anders Peterson.

Linköping University

When several trains are planned to use the same infrastructure resource, there is always a risk for spreading of delays, which can be hard to recover from. It is a challenge for the Infrastructure Manager to make timetables that accommodate as much traffic as possible, without causing bad on-time performance. Timetable planners are in need of quantitative indicators to assess timetable robustness and accurate methods for how to make the timetable more robust. In this paper we assess the robustness for single-track lines with non-periodic timetables. At single-track lines, trains use the line for running in both directions and the trains can only pass or overtake each other at passing loops. This makes the system more sensitive for delays. In this paper we present a robustness indicator which captures the dependencies between trains at a single-track line. The indicator can be used to illustrate weaknesses in a timetable and also to indicate where and how to insert more robustness. In a simulation study, we show that it is possible to improve the performance by making small timetable adjustments according the indicator, without increasing runtimes or capacity utilization.

Keywords
Timetabling, Robustness, Single-track, Indicators

Session 1.3B: Train delay prediction
Submission type: Research paper
Presentation type: Oral
Paper ID: [89]

Non-stationarity in Train Delay Propagation Analytics Based on Markov Chains

Thomas Spanninger and Francesco Corman.

ETH Zurich

Markov chain models have been applied extensively in context of descriptive and predictive train delay propagation analytics. One of the main reason for Markov chains becoming popular in this context is their simple and demonstrative method of modelling the dynamics of railway system based on simplifications on the dependency structure of train-events (i.e., arrivals and departures). They also allow the exploitation of historic train movement observation in a data-driven modelling style. Markov chains convince in terms of interpretability by providing transition probability matrices for predefined states of delay. Therefore, Markov chains can be regarded a stochastic baseline prediction approach for train delays. They are also often used to provide descriptive analytics of delay propagation in railway systems. In this study, we analyze the widely used stationarity assumption of Markov chains in context of train delay propagation analytics (i.e., the assumption that the transition probability matrices for all processes are equal). We introduce twenty increasing levels of non-stationarity. We show in an application within the Swiss railway network that the relaxation of the location-based homogeneity assumption of stationarity is by far the most important relaxation in comparison to process-, direction-, line- and time-specifications of transition probabilities. This highest level of non-stationarity reduces the mean absolute error of the prediction substantially by more than 55\% compared to the stationary Markov chain model.

Keywords
Train delay, Markov chain, Non-Stationarity, Prediction

Session 2.1B: Railway traffic management and rescheduling I
Submission type: Research paper
Presentation type: Oral
Paper ID: [90]

An Approximate Conflict Detection and Resolution Model for Moving-Block Signalling by Enhancing RECIFE-MILP

Nina D. Versluis[a], Paola Pellegrini[b], Egidio Quaglietta[a], Rob M.P. Goverde[a] and Joaquin Rodriguez[b].

[a] *Delft University of Technology,*
[b] *Université Gustave Eiffel*

Conflict detection and resolution models are being developed to support railway traffic management in taking optimised rescheduling decisions in case of disturbances. Existing models mostly concern fixed-block signalling systems, in which minimum train separation distances are determined based on a preset number of blocks representing worst-case braking distances. In a moving-block signalling system, minimum train separation is based on absolute braking distances and hence depends on train speed differently from how fixed-block conflict detection and resolution models. In this paper, we propose a conflict detection and resolution model that approximates moving-block operations. The model enhances the state-of-the-art fixed-block rescheduling model RECIFE-MILP. The enhancements include a reconsideration of the discretisation of the infrastructure, the introduction of a speed profile alternative and a redefinition of the blocking times. We verify the model by comparing the solutions of the moving-block version with the fixed-block version for a specific scenario. The results indicate that the moving-block model can propose different rescheduling decisions than the fixed-block model with a better delay recovery.

Keywords
Railway traffic management, Conflict detection and resolution, Rescheduling, Moving-block signalling, Mixed integer linear programming

Session 2.1A: Railway performance II
Submission type: Research paper
Presentation type: Oral
Paper ID: [92]

Railway Traffic Optimization: Robustness to Driving Behaviour Noise

Bianca Pascariu[a], Balraj David[b], Paola Pellegrini[a] and Grégory Marlière[a].

[a] *Université Gustave Eiffel,*
[b] *ENTPE*

The real-time Railway Traffic Management Problem (rtRTMP) is a classical problem in the field of railway operations research. It consists in defining the passing orders and the arrival and departure times of trains in stations and selecting their route across the network. The aim is to minimize delay propagation, given a perturbed timetable. Several models and algorithms have been developed to solve this problem and provide optimized decision support systems. However, most of the systems have been tested in controlled environments without considering the train movement uncertainties that might be encountered in real implementation. For example, train driving behaviour is a source of noise for train operations that can significantly alter the traffic predictions used in the rtRTMP. In this paper, we study the robustness of the rtRTMP solution in terms of its ability to cope with train operations noise, which is inevitable in practical deployment. We consider a closed-loop framework that integrates OpenTrack, a commercial railway traffic simulator, with RECIFE-MILP, an rtRTMP solver. The solver periodically communicates with the simulator, providing optimized traffic management decisions for a given time horizon and receiving traffic feedback. The quality of traffic management decisions made in closed-loop is compared to the application of the First Come First Serve (FCFS) approach. Moreover, we compare the former with the use of RECIFE-MILP in open-loop, i.e., performing a single traffic management optimization at the beginning of the time horizon and sticking to the decisions made for the whole time. Computational experiments are performed on a portion of the French rail line between Paris and Le Havre. The analysis shows that the closed-loop rtRTMP framework significantly enhances solution robustness by reducing the impact of noise on total delay.

Keywords
Real-time Railway Traffic Management, Train Scheduling and Routing, Empirical Analysis, Robustness

Session 1.1C: Passenger assignment
Submission type: Research paper
Presentation type: Oral
Paper ID: [93]

Demand Responsive Service in Railway: A Framework to Realize by Flexible Train Timetable

Songliang Zhang, Dewei Li and Yaqiong Zhao.

Beijing Jiaotong University

For railway system, passengers and operators have irreconcilable information asymmetry with each other. Passengers may be crowded at some time and operators are unable to provide adequate capacity to service. To solve this problem, we put forward a framework to offer demand responsive service by flexible timetable. Trains may operate at different time every day within a specific time window, and the exact operating time for one train in a particular day will be determined according to passengers' actual travel demand on that day. This will meet various passenger demand, which is based on an advanced trip reservation system with regulation of reservation and customization. Passengers can submit their travel demand in this way at any time and flexible timetable will be optimized. Reserved passengers can receive travel feedback according to their personalized demand. This pattern will improve passengers' satisfaction with railway and operating revenue.

Keywords
Railway timetable, Demand responsive service, Passenger demand

Session 2.1A: Railway performance II
Submission type: Research paper
Presentation type: Oral
Paper ID: [94]

Restoration time for corrective maintenance on the Swedish railway network

Grace Mukunzi[a], Emil Jansson[b] and Carl-William Palmqvist[a].

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[b] *KTH Royal Institute of Technology*

Operationally, preventative maintenance, which is planned well in advance, is the most ideal. However, the need for corrective maintenance is inevitable. With the goal of an increased modal share for train traffic (both passenger and freight), the wear of the infrastructure and associated random failures will increase due to an increase in train movements. Thus corrective maintenance needs to be handled as soon as possible. i.e., short response times and short repair times to minimize network delays. In this study, factors influencing restoration times (response times and repair times) have been studied based on five years of failure reports from the Swedish railway network. The median response time is 41 minutes and 83% of all failures are responded to within 2 hours. The median repair time is 80 minutes and the median restoration time is 159 minutes. The results show that failure type has a higher influence on the restoration time than the geographical location of the failure. 93% of accidents/incidents are restored within 2 hours while only 37% of track failures are restored within 2 hours. The results of the restoration time showed geographical differences, however, without any clear correlation between rural or metropolitan areas, both the shortest and the longest restoration times were in rural areas in the north of Sweden. Temporal factors (months) were seen to have minimal impact on restoration time. These results provide insight into factors that influence the performance of corrective maintenance and may be used as a basis for the development and improvement of railway disruption management protocols.

Keywords
Railway, Restoration time, Corrective maintenance, Response time, Repair time

Session 1.3A: Railway capacity I
Submission type: Research paper
Presentation type: Oral
Paper ID: [95]

Solving the Timetabling and Routing with Order Constraints Problem to Optimize Railway Capacity Utilization

Inneke Van Hoeck and Pieter Vansteenwegen.

KU Leuven

In heavily used railway networks, it is crucial to utilize the available capacity as efficiently as possible. In this paper, the Timetabling and Routing with Order Constraints Problem is considered. In this problem, the current timetable can be adjusted by changing both the timings and the routes of the trains, while specific order constraints are imposed. The objective is to maximize the smallest buffer times between trains in the network to improve the robustness. A MILP model that represents this problem is given. Due to computational limitations, a heuristic approach is suggested to solve the problem. Two zones in a complex part of the Belgian network are considered in the case study. For these zones, the heuristic allows to increase the minimal buffer time with a percentage of 26.19% and 128.21%, respectively.

Keywords
Capacity usage, Timetable robustness, Timetabling, Routing

Session 1.3C: Energy saving in railways
Submission type: Research paper
Presentation type: Oral
Paper ID: [96]

Lagrangian relaxation based speed profile optimization for multiple trains under virtual coupling with operational state transition

Songwei Zhu[a], Yihui Wang[a], Shaofeng Lu[b], Andrea D Ariano[c] and Lingyun Meng[a].

[a] *Beijing Jiaotong University),*
[b] *South China University of Technology*
[c] *Roma Tre University*

To increase the capacity of rail transit, the virtual coupling train operation is proposed. With the development of vehicle-to-vehicle communication technology and signalling technology, the virtual coupling operation will come true in the future. The operation under virtual coupling is different from the ordinary moving-block operation, so it is of great importance to investigate the speed profiles optimization for multiple trains under virtual coupling. In this paper, a mixed integer nonlinear programming model is proposed to describe the train operation under virtual coupling, where the states of virtual coupling are denoted by binary variables. The nonlinear model is transformed into a mixed integer linear programming model by a piecewise-linear method, so that the problem can be solved by existing solvers. In some scenarios where the distance between two trains will decrease, the constraints of safety distance make the problem hard to solve. To enhance the computational efficiency, a Lagrangian relaxation method is proposed to deal with the constraints of safety distance. Based on the data of Beijing-Shanghai high-speed railway, numerical experiments are conducted to demonstrate the effectiveness of the proposed methodology in coupling and decoupling scenarios. The results indicate that the proposed model can be used to optimize the speed profile for multiple trains under virtual coupling, and the Lagrangian relaxation method can achieve better performance than solving the problem by CPLEX directly in the coupling scenario.

Keywords
Trajectory optimization, Virtual coupling, High-speed railway, Mixed integer linear programming

Session 2.4C: Rail freight transport II
Submission type: Research paper
Presentation type: Oral
Paper ID: [97]

Data-driven based circular train design of railway freight transportation

Yuan Chen, Minyi Cai, Haodong Li and Jiaqi Ding.

Beijing Jiaotong University

Circular train is a type of rail freight product that service specific freight stations circularly with the fixed railcars. The organization of circular can not only improve the level of service, but also promote the utilization of resources such as railcars to increase the efficiency of freight transportation. This paper develops a data-driven framework to design circular trains based on loading data of China Railway network. This framework first identifying the potential freight demand that may organize circular train during the plan horizon. The OD (Original and Destination) of those demand are transformed into nodes, and then an optimization model for circular train organization is proposed based on multiple traveling salesman problem (MTSP). A case study based on historical data from China Railway demonstrate that the proposed solution method yields the optimal circular trains organization plan.

Keywords
Railway freight transport, Circular train design, Data-driven, Demand analysis, DBSCAN algorithm

Session 2.5A: Timetabling III
Submission type: Research paper
Presentation type: Oral
Paper ID: [98]

Coordinated train rerouting and rescheduling in large infrastructures

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[c] *Universita Ca' Foscari Venezia*

Railway traffic controllers often face the problem that trains do not operate as planned in their timetables because of perturbations caused by unexpected, degraded operations, e.g., due to technical failures. This paper deals with a coordinated train rerouting and rescheduling problem to minimize the impact of perturbations, i.e., to minimize delay propagation. We consider the problem of coordinating traffic management across different control areas, which is modeled as a two-level optimization problem. We assume that the second level controllers, the dispatchers, manage train schedules and routes in their own control areas from a microscopic perspective. The first level controller, the coordinator, optimizes traffic and ensures the compatibility of dispatchers' decisions over two or more areas from a macroscopic perspective. We propose an iterative solution algorithm for the optimization problem. In this algorithm, infeasibilities and delays are detected. We provide computational results and discussions at the end.

Keywords
Real-time traffic management, Perturbations, Coordination problem, Dispatching problem, Iterative algorithm

Session 3.1B: Rolling stock and crew scheduling II
Submission type: Research paper
Presentation type: Oral
Paper ID: [99]

Towards a Generic Heuristic Approach for the Real-Time and Automatic Schedule Adjustment

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Institute of Railway Engineering, Technical University of Darmstadt

In the context of the current digitalization of railway operations towards a more effective and efficient utilization of the available capacity, decision-support systems for dispatching have become key assets. The execution of scheduled railway operations is characterized by the adjustment of the existing schedule to the occurrence of stochastic events. Due to the complexity of the schedule adjustment process, a series of decision-support tools have been developed to assist dispatchers in real-time. Given their flexibility, heuristic methods arguably stand as the most relevant alternative to constitute such tools. The contribution of this article is aimed at deriving a generic (i.e. generally applicable) heuristic approach that supports the automatic and real-time adjustment of scheduled railway operations. To achieve the proposed aims, a systematic review of existing literature is conducted. All the approaches retrieved from the literature are carefully analysed, categorized and processed to identify the widest set possible of processes and frameworks. The results from the analysis are utilized to derive the sought generic heuristic approach. Ultimately, an example of the implementation of the proposed generic heuristic approach in a praxis-relevant situation is provided. This study provides outstanding entry points for further conducting experimental research.

Keywords
Rescheduling, Schedule Adjustment, Conflict-Detection, Conflict-Resolution, Heuristic

Session 2.1A: Railway performance II
Submission type: Research paper
Presentation type: Oral
Paper ID: [100]

Maximizing railway punctuality: A microsimulation evaluation of robust timetabling methods

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[b] *Mälardalen University*

Punctuality is commonly recognized as one of the most important quality indicators for passenger traffic. Despite this, surprisingly few methods for explicitly maximizing punctuality by optimizing the timetable exists in the literature. We study how late-stage adjustments during the capacity allocation can improve punctuality of the traffic. In this paper, we therefore extend a combined simulation-optimization method so it can be used to explicitly maximize the predicted punctuality of a given nonperiodic timetable on a double-track line. The method is evaluated in two microsimulation experiments in the southbound direction of the Swedish Western Main Line using Railsys. We compare the method in simulation with our previous method for minimizing total disutility, two methods from the scientific literature (light robustness, and robustness in critical points) and two naïve strategies. The methods' effectiveness is assessed in a detailed statistical analysis considering end-station punctuality, total punctuality, and the robustness measure total disutility. Only light robustness results in timetables that in simulation performs better or equally well as the given timetable (based on the national timetable) with respect to all performance measures and evaluated scenarios. The method for maximizing punctuality performs best with respect to total punctuality.

Keywords
Timetabling, Train scheduling, Railroad, Robustness

Session 2.3C: Rail freight transport I
Submission type: Research paper
Presentation type: Oral
Paper ID: [101]

Application of Simulation-assisted Machine Learning for Yard Departure Prediction

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[a] *KTH Royal Institute of Technology*
[b] *University of Texas at Austin*
[c] *Mälardalen University*

Increasing the modal share of rail freight is an ongoing goal in Europe and North America. Yards can play an important role in realizing this target by their reliable and predictable performance. We aim at predicting yard departures by implementing a simulation-assisted machine learning model via two general and step-wise concepts for including the predictors. The former adds all predictors at once, and the latter adds them per the availability or the sub-yard. The data used for training the model is a one-year real-world operational data set from a European hump yard and multiple two-year simulation data sets from a representative hump yard in North America. To the best of our knowledge, no previous research has attempted to implement a generalizable prediction model between the European and the North American contexts. The model is developed on a decision tree algorithm based on a 10-fold cross-validation process. Comparing the model performance on three data sets: the real-world, a baseline simulation, and an ultimate randomness simulation shows that the model has a similar performance in the first two data sets with a respective R-squared of 0.90 and 0.87, which shows high capturing of the variance in the data. However, adding large randomness in the simulation decreases the R-squared to 0.70. Results for the step-wise inclusion of the predictors are different for the real-world and simulation data. For the former, adding more operational predictors does not change the model performance, whereas for the latter, adding departure yard predictors increases the R-squared substantially. The global feature importance shows that for the real-world data almost all predictors contribute to a great extent to the predictions, with maximum planned length, departure week day, and the number of arriving trains as the most contributing ones, whereas for the simulation data, the departure yard predictors provide the largest contribution.

Keywords
Yards, machine learning, simulation, delay prediction, rail freight

Session 3.1B: Rolling stock and crew scheduling II
Submission type: Research paper
Presentation type: Oral
Paper ID: [102]

A Hybrid Bogie Maintenance Approach to Optimize Railway Fleet Availability

Mariana De Almeida Costa[a], Tiago Alves[b], António Ramos Andrade[b] and Francesco Corman[a].

[a] *ETH Zurich*
[b] *IDMEC - Instituto Superior Técnico, University of Lisbon*

Railways are a reliable, efficient and low-pollution solution for the mass transportation of passengers and goods. This imposes high demands on service quality, resilience against failures and cost-effectiveness. The increasing demand for sophisticated and flexible models for the improvement of the maintenance decision-making process in railways fuels research that largely exploits the use of data analytics and optimization tools, where availability and safety are of utmost concern. With the current advancements in technologies to acquire and process failure data, a large amount of event data and condition monitoring data are available, making it possible for railway providers to shift from the traditional maintenance paradigm consisting of corrective and preventive maintenance tasks to more-flexible maintenance strategies that also incorporate other types of maintenance tasks. This paper provides a case study on the optimization of the availability of a small fleet of locomotives of a train operating company operating in Catalonia, Spain. The model aimed to study the viability and measure the expected economic returns of shifting from a complete preventive maintenance program to a hybrid program incorporating condition-based and predictive maintenance tasks in selected components of the locomotives' bogie. A deterioration model along with failure rate estimation was proposed and integrated into the optimization formulation, and the scheduling model was tested for a 4-year interval. The framework was able to mimic current maintenance practices and show that shifting to a hybrid maintenance plan resulted in reduced unavailability costs.

Keywords
Railway Maintenance Scheduling, Rolling Stock Bogie, Mixed-Integer Linear Programming, Degradation Model, Reliability Analysis

Poster session
Submission type: Research paper
Presentation type: Poster
Paper ID: [103]

Line Planning for Time-Varying Passenger Demand in Railways

Viera Klasovitá and Francesco Corman.

IVT ETH Zürich

We consider the problem of line planning for a public transport network. We focus on railways as it is more constrained by the availability of infrastructure and overtakes along the infrastructure resources. We look at the extension to evaluate demand which is variable across time. As a goal, we want to keep the nice solution of having a single line plan throughout the demand variations. Formally, we study a periodic line plan, with a set of lines that repeat a given amount of times (frequency) in a given period. Each line has also a given stopping pattern. The frequency and stopping pattern can vary across periods in our variable demand extension. Therefore, we design a multi-stage optimisation model to describe this situation and indicate possible ways to solve it. We comment on the relevance of such a solution.

Keywords
Line planning, demand, multi-stage approaches, mathematical optimisation

Session 1.3C: Energy saving in railways
Submission type: Research paper
Presentation type: Oral
Paper ID: [105]

Coasting advice based on the analytical solutions of the train motion model

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[a] *TU Delft),*
[b] *Nederlandse Spoorwegen*

A large variety of supervision, data analysis and communication algorithms monitor trains, exploiting most of their available computational power. On-board eco-driving algorithms such as Driver Advisory Systems are no exception, as the computational power available can limit their complexity and features. This was the case of Roltijd, the in-house developed Driver Advisory System based on coasting advice of Nederlandse Spoorwegen (NS), the main Dutch passenger railway undertaking. This platform calculated the coasting curves at every second by integrating the equations of motion numerically, assuming that the track is flat. However, the plans of NS regarding generating more complex driving advice require replacing this coasting curve calculation by a more computationally-efficient algorithm. In this article we propose a new coasting advice algorithm based on the analytical solutions of the train motion model's differential equations that assumes the gradients and speed limits as piecewise constant functions of the train location. We analyze the qualitative properties of these solutions using the theory of dynamical systems, showing that bifurcations arise depending on the value of the gradient and the applied tractive effort. We validate the proposed algorithm by comparing its performance and accuracy against the previous method and a train trajectory optimizer based on a pseudospectral method, finding that our algorithm is accurate and can be 15 times faster than the previous method. This allows NS to implement the proposed method on the trains running in the Dutch railway network, contributing daily to the sustainable mobility of 1.3 million passengers.

Keywords
Driver Advisory Systems, Eco-driving, Coasting, Differential Equations, Railways

Session 1.1A: Timetabling I
Submission type: Research paper
Presentation type: Oral
Paper ID: [107]

Periodic Timetabling with Integrated Track Choice for Railway Construction Sites

Berenike Masing[a], Niels Lindner[b] and Christian Liebchen[c].

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[b] *Freie Universität Berlin*
[c] *Technische Hochschule Wildau*

We propose a mixed-integer linear programming model to generate and optimize periodic timetables with integrated track choice in the context of railway construction sites. When a section of a railway network becomes unavailable, the nearby areas are typically operated close to their capacity limits, and hence carefully modeling headways and allowing flexible routings becomes vital. We therefore discuss first how to integrate headway constraints into the Periodic Event Scheduling Problem (PESP) that do not only prevent overtaking, but also guarantee conflict-free timetables in general and particularly inside stations. Secondly, we introduce a turn-sensitive event-activity network, which is able to integrate routing alternatives for turnarounds at stations, e.g., turning at a platform vs. at a pocket track for metro-like systems. We propose several model formulations to include track choice, and finally evaluate them on six real construction site scenarios on the S-Bahn Berlin network.

Keywords
Railway Timetabling, Periodic Timetabling, Periodic Event Scheduling, Train Routing, Turnarounds

Session 1.1A: Timetabling I
Submission type: Research paper
Presentation type: Oral
Paper ID: [109]

Joint Optimal Periodic Timetabling and Train Routing

Florian Fuchs[a] and Francesco Corman[b].

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[b] *ETH Zurich*

Timetabling and selecting routes for trains are two inherently related topics, as one affects the possible solutions of the other. While considering the problems independently brings the advantage of comparably easier stand-alone problems, it might come at a high cost of wasted capacity and unsatisfactory quality. Thus, we consider both planning problems simultaneously. Besides, we aim to provide exact solutions and model infrastructure topologically accurate on a mesoscopic level. Besides accuracy, optimality is part of our scope. Thus, we model the problem as a mixed integer problem.
However, as we combine two problems that are already challenging when considered independently, we provide several means to reduce the size of the instance and measures to strengthen the formulation. While these improvements positively affect computation time, they do not affect solution quality. Thereby, we conserve optimality. As a result, our approach provides simultaneously optimised timetables and train routes.
We assess our proposition on real-life instances of varying size and network utilisation. The results underline the drastic effect of our strengthening propositions, as we report a speed-up of more than two orders of magnitude in small instances. For more extensive instances where no optimal solution can be found within the time limit, reducing and strengthening yields higher quality solutions and optimality gaps of less than half the value when compared against the non-reduced/strengthened formulation.

Keywords
Railway timetabling, Integrated optimisation, Timetabling and train routing, Railway planning

Session 2.3B: Railway signalling and control systems
Submission type: Industrial paper
Presentation type: Oral
Paper ID: [110]

Assessing the performance of tramway junctions with the mutualisation of rail signalling

Guillaume De Tiliere, Quentin De Cacheleu and Florian Bonet.

EGIS Rail

In the case of complex tramway networks, traffic light junctions in dense cities are complex nodes for users and are generally synonymous of wasted time: Junctions are critical in the performance of tramway lines and the robustness of transport plan, especially in pick hours. With a view to continuous improvement, our EGIS teams have been looking for ways to optimise the junctions of tomorrow. In 2022, a study on simplified manoeuvring zones was carried out with the Lyon tramway, and a deployment is being carried out on the Angers tramway in France. The present article present the results of the simulation of operation of cross sections, based on VISSIM simulation software. The results will allow to better understand how the performance of tramway network operation at such junctions could be affected by the mutualisation of rail signalling.

Keywords
Tramway junction operation, junction capacity, Tram priority, rail signalling

Session 2.3A: Rolling stock and crew scheduling I
Submission type: Research paper
Presentation type: Oral
Paper ID: [111]

Shift Scheduling for Train Dispatchers

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Linköping University

Train dispatchers monitor and control train traffic from a dispatching center, which is responsible for a certain region in the railway network. This region is divided into subareas, where each train dispatcher controls one or several subareas at any time. Given the high safety concerns of their profession, dispatchers' working shifts should fulfil several legal and operational constraints, such as bounds on the length of shifts and on the resting periods between shifts. To construct shift schedules for train dispatchers is a complex and time-consuming process that is currently done manually. In this paper, we present an optimization framework to automate this process, based on a model for single-day shifts. Here, we focus on the objective of minimizing the number of dispatchers as a baseline for future objectives. We present experimental results for real-world sized data (number of geographical areas and train movements in the order of magnitude as for one dispatching center in Sweden, covering the southern part of the country). We study the impact on the run time for different input parameters, namely: the total number of geographical areas, the maximum number of geographical areas that can be assigned to a dispatcher in any period, changes in adjacency between the geographical areas, and the number of geographical areas that each dispatcher is qualified to monitor. The run time for the instances is between 19 and 305 seconds.

Keywords
Integer Programming, Shift scheduling, Railway dispatching, Area combination

Session 1.2C: Railway maintenance planning and scheduling
Submission type: Research paper
Presentation type: Oral
Paper ID: [113]

Approximating the Rolling Stock Rotation Problem with Predictive Maintenance by a State-Expanded Event-Graph

Felix Prause, Ralf Borndörfer, Boris Grimm and Alexander Tesch.

Zuse Institute Berlin

We study the solution of the rolling stock rotation problem with predictive maintenance (RSRP-PM) by an iterative refinement approach that is based on a state-expanded event-graph. In this graph, the states are parameters of a failure distribution, and paths correspond to vehicle rotations with associated health state approximations. An optimal set of paths including maintenance can be computed by solving an integer linear program. Afterwards, the graph is refined and the procedure repeated. An associated linear program gives rise to a lower bound that can be used to determine the solution quality. Computational results for two instances derived from real world timetables of a German railway company are presented. The results show the effectiveness of the approach and the quality of the solutions.

Keywords
Rolling Stock Rotation Planning, Predictive Maintenance, Integer Linear Programming, Heuristic, Lower Bound

Session 3.2B: Passenger flows
Submission type: Research paper
Presentation type: Oral
Paper ID: [115]

Dwell-time Station-Service analysis using Rasch analysis technique

Ruben A. Kuipers[a], Natchaya Tortainchai[b], Neba C. Tony[b] and Taku Fujiyama[b].

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In order to ensure a punctual and robust service it is vital to schedule the appropriate dwell times. Current dwell time scheduling practices are mostly based on general assumptions and lead to actual dwell times exceeding scheduled dwell times on a regular basis. This study is a first step into using the Rasch analysis to compare the relative dwell time performance of stations and services. We assess the applicability of the method, using dwell time records from commuter trains in Sweden and the UK. The good model fit suggests that it is feasible to apply the Rasch analysis to dwell times. Using the output of the model we identified that basing dwell times on passenger volumes or average dwell times does not reflect the actual performance. Combining the dwell time performance of stations and services we found that the Rasch analysis can identify where to alter the scheduled dwell times. We concluded that the Rasch analysis can be used in dwell time analyses and the outcome can be beneficial for planners in identifying where adaptations to the dwell time would be necessary.

Keywords
Dwell time, Rasch analysis, Service, Station, Railway

Session 2.1B: Railway traffic management and rescheduling I
Submission type: Research paper
Presentation type: Oral
Paper ID: [116]

Goal-oriented Self-Organization in Railways

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TUDelft

This paper reviews the concept of self-organisation as defined in different fields and attempts to provide a definition of goal-oriented self-organization that can be applied in the context of railway traffic. Based on the provided definition a modelling approach for self-organising rail traffic is then proposed to set the basis for future research and exploration of such a concept which could revolutionise the current rail transport to meet long-term capacity and competitiveness goals envisaged by the railway industry.

Keywords
Self-organization, Railway Traffic Management, Common Pool Resource

Poster session
Submission type: Industrial paper
Presentation type: Poster
Paper ID: [117]

Assessing self-organization algorithms for railway traffic: the selection of three case studies for the SORTEDMOBILITY research project

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SORTEDMOBILITY is a research project investigating feasibility, benefits, and challenges of the application of self-organizing principles and algorithms in railway operations. The proposed algorithms are being tested in different settings, focusing on the applicability and results in different context. Three case studies were selected and modelled, each with its peculiar operational settings. A local railway line in the French Brittany with very sparse traffic is selected to assess possible reductions in operational costs while keeping or improving the service quality. A section of a main line in Lombardy, Italy, is selected to the assessment in more complex settings, possibly interfacing with incomplete deployment of the technologies, and with different stakeholders involved in the negotiations. Finally, the complete suburban railway network of Copenhagen, Denmark, is used for a full-scale test, with high-detailed data availability, homogeneous operations, and very dense traffic. This paper describes the cases and relative adaptations and provides information for the replicability of the validation. The suitability for the research project and the focus area is discussed for the cases individually.

Keywords
SORTEDMOBILITY, Case Studies, Simulation, Operational principles, Assessment

Session 1.3A: Railway capacity I
Submission type: Research paper
Presentation type: Oral
Paper ID: [119]

Modelling Time in the Timetable-Based Railway Network Design Problem

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Due to long planning periods, the planning procedure for railway infrastructure starts long before the planning of the intended operation. Hence, the options for scheduling the trains in later steps are quite restricted as short-term infrastructure expansions are problematic. Therefore, each, usually expensive, modification should be done considering the unknown future demand as best as possible.
Here, we provide a model for the network design problem for railway infrastructure under capacity constraints and uncertain timetables. In this paper, we plan the infrastructure measures based on a strategic timetable to investigate the possibilities for adapting the traditional railway network design process to changing demands.
This problem is similar to the fixed-charge network design problem. We minimize the expansion costs while respecting certain timetable constraints. We model the problem as an integer linear program. First, we model the departure and arrival times as variables and secondly, we apply a time-expanded network.
We present the linear integer formulations for both approaches and discuss the differences in the applicability as well as in the computational results.

Keywords
Network Design, Robust Optimization, Railway Planning, Railway Network Design, Strategic Timetabling

Poster session
Submission type: Research paper
Presentation type: Poster
Paper ID: [120]

Initiating Wireless Railway Network Planning with FRMCS in Croatia

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Up-to-date radio communication technology known as the Future Railway Mobile Communication System (FRMCS) will soon replace the outdated GSM-R communication component on conventional and high-speed railways worldwide. This will contribute to higher operational safety, reliability and robustness while supporting existing and new railway applications, but also digitise the railway sector, making it more competitive among other modes. In the absence of precise migration strategies, this paper explores FRMCS implementation possibilities on the example of the Croatian railway network, which does not have GSM-R-based train control, but still uses an outdated radio dispatch system. Priority of FRMCS implementation is given mainly to main lines of international importance. Moreover, results show that choosing 900MHz-only and -partial implementation with an additional 1900MHz layer where necessary, would cost 50% of the 1900MHz implementation cost and 40% of the dual-layer implementation cost. Here demonstrated "greenfield" FRMCS deployment is practical not only for countries without GSM-R network, but also for those whose railway lines are partially equipped.

Keywords
FRMCS, Croatian railway network, railway communication system, implementation steps

Session 1.3C: Energy saving in railways
Submission type: Research paper
Presentation type: Oral
Paper ID: [121]

Real-time Mitigation of Power Peaks in Railway Networks using Train Control Measures

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Power peaks are an undesirable phenomenon occurring in railway networks when multiple trains require large amount of power simultaneously, for instance during acceleration. This phenomena puts too much pressure into the power grid, which in the worst cases it can result into a blackout, and hence it represents a relevant concern for operators. One solution for this is fine-tuning of timetables to minimize power peaks. Nevertheless, the benefits of adjusted timetables can be lost in situations with train delays in the network. In this paper, we develop a simulation-based optimization approach to mitigate anticipated power peaks in real-time by means of train control measures, i.e. traction power limitation and departure time shift, combined with real-time rescheduling. To do this, we propose a discrete-event simulation model for real-time traffic management in railways and we use precomputed train trajectories and power consumption profiles. We demonstrate the performance of the approach developed in a real-life case in a part of the Swiss Federal Railways network. The results show the potential of train control measures to mitigate power peaks above a given power target value with small adjustments in train runs and low delay induced.

Keywords
Power peaks, Rail traffic management, Railway simulation, Train control, Mixed-integer linear programming

Session 1.2B: Railway safety analysis and risk assessment
Submission type: Research paper
Presentation type: Oral
Paper ID: [122]

Failure mode and effects analysis of rail turnouts under fuzzy environment

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Failure mode and effects analysis (FMEA) is a widely used risk assessment tool for defining, identifying, and eliminating potential failures or problems in products, process, designs, and services. In traditional FMEA, the risk priorities of failure modes are determined by using risk priority numbers (RPNs), which can be obtained by multiplying the scores of risk factors like occurrence, severity and detection. In this paper, linguistic variables, expressed in triangular fuzzy numbers, are used to assess risk ratings of failure modes and the weights of risk factors. For selecting the most serious failure modes, the extended VIKOR method is used to determine risk priorities of the failure modes that have been identified. As a result, a fuzzy FMEA based on fuzzy set theory and VIKOR method is proposed for the prioritization of failure modes, specifically intended to address some limitations of the traditional FMEA. In the case study, the elements of the turnout were observed and a model was applied over them, where the goal is to get the ranking of the critical elements.

Keywords
Failure mode and effects analysis (FMEA), Fuzzy set theory, VIKOR method, Risk factors, Turnouts

Session 2.5C: Railway simulation and digital twins
Submission type: Research paper
Presentation type: Oral
Paper ID: [125]

Evaluating Car-to-Train Assignment Strategies for the Railway Marshalling yard using a Multi-Agent Simulation Approach

Zhuang Li[a], Hongxiang Zhang[b], Wen Wen[a], Bisheng He[a], Yuan Wang[c] and Gongyuan Lu[a].

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[c] *University of South Florida*

Optimizing car-to-train assignment decisions in marshalling stations is a significantly effective way of coping with the massive railway freight volume and improving railway transportation efficiency. This paper proposes a series of heuristic car-to-train assignment strategies to reduce car dwell time and increase the number of outbound trains. The heuristic strategies focus on adjusting the hump sequence of inbound trains and assigning decoupled cars to classification tracks. To evaluate these strategies, a multi-agent simulation model of the marshalling station operation is developed based on a topological layout representation method, a path planning method for train movements, and a route conflict elimination mechanism. The numerical experiment shows that the multi-agent simulation can effectively simulate various operation processes in the marshalling station. The proposed heuristic car-to-train assignment strategies achieve promising results in reducing car dwell time and increasing outbound trains.

Keywords
Railway marshalling station, Car-to-train assignment, Heuristic strategy, Multi-agent simulation

Session 1.3B: Train delay prediction
Submission type: Research paper
Presentation type: Oral
Paper ID: [126]

Train Delay Prediction via Transformer-based Deep Learning Model

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[b] *Roma Tre University*
[c] *University of Electronic Science and Technology of China*

Accurate prediction of train delays can assist the railway dispatchers in ensuring railway punctuality, which maintains a high service level of railway. As various factors could arouse train delays, the prediction task is always a significant challenge in academia and industry. In this paper, we propose a Transformer-based Deep Learning (TDL) framework to predict train delays. In the model, one Transformer Network(TN) deals with a series of the historical section running time, another TN fits a series of trains' features of the current station, and a Fully Connected Network(FCNN) handles the weather data. Then, the final prediction result is obtained by fusing the above output of networks. A real-world data of Guangzhou South and Shenzhen North section is tested to validate our proposed method. The experimental results demonstrate that our model outperforms the baselines, which indicates the effectiveness of the feature engineering and the use of TN to capture information in train operation time series.

Keywords
High speed rail, Train delay prediction, Deep learning, Transformer, Historical section running delay

Session 1.1B: Emerging railway technologies
Submission type: Research paper
Presentation type: Oral
Paper ID: [127]

An Agent-based Simulation System for the Operations of Railway Marshalling Yard

Bisheng He[a], Yanbo Yin[a], Bo Jian Zhang[a], Peng Chen[b] and Gongyuan Lu[a].

[a] *Southwest Jiaotong University*
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As an environmentally friendly and efficient transportation mode, freight rail transportation faces a decrease in market share in recent years. Since the marshalling yard occupies twothirds of the total transportation time, it is crucial to improve its efficiency and decrease the total railcar dwell time inside the yard. Due to the multi-types of task including the arrival and departure of trains, disassembly, marshalling, assembly, and the corresponding operations of locomotives involved, the operation of marshalling yard is challenging. In this paper, we present an agent-based marshalling yard simulation model. The simulation, that models complicated operations from inbound arrivals, disassembling, assembling, to outbound departures, is implemented with a dynamic routing mechanism of moving units, multi-stage disassembly with flexible use of classification track, and mixed assembling strategy with fixed length and fixed time through the agent-based technology. The experiments on an actual marshalling yard verify the validation of simulation, and the effectiveness of proposed measures.

Keywords
Agent-Based Simulation, Marshalling Yard Operation, Freight rail transport, Mulit-stage disassembly, Routing and scheduling

Poster session
Submission type: Research paper
Presentation type: Poster
Paper ID: [128]

Simplified Train Consist Planner to Drive Simulations of Alternative Energy Locomotive Deployment Strategies to Lower the Carbon Emissions of Freight Rail Transportation

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[a] *University of Illinois at Urbana-Champaign*
[b] *University of Texas at Austin*

Efforts to decarbonize freight rail transportation powered by diesel-electric locomotives require railroad practitioners to make difficult decisions regarding the development and future deployment of alternative energy technologies. New decision-support tools are required to determine the set of technologies to develop and identify the network of mainline corridors to deploy them on such that the carbon-emissions benefits of these large capital investments are maximized. This paper describes development of a simplified train consist planner that is one component of a larger simulation-optimization model designed to evaluate alternative energy locomotive implementation scenarios. After reviewing previous research on train planning practices, a new simplified framework is constructed that includes freight traffic demand processing, train scheduling, and locomotive assignment in a simulation approach. Python is used to construct the train planning simulation framework, and user inputs are well defined to avoid misuse but still provide great freedom for scenarios involving different traffic demands, locomotive characteristics, simulation timespan, and network size. This flexibility is particularly important given that many alternative-energy freight locomotives of the size and power required for North American mainline service are still at the prototype stage of development, and their detailed parameters and operating characteristics are still subject to change. When combined with other modelling and economic decision modules under development, the simplified train planner will function as the initial stage of an advanced framework to quantify the impact of alternative locomotive technology deployment over multiple years and provide insightful and thorough analysis for a wide range of user-specified scenarios.

Keywords
Locomotive assignment, Operating strategy, Simulation, Train planning, Alternative energy

Session 2.5C: Railway simulation and digital twins
Submission type: Research paper
Presentation type: Oral
Paper ID: [129]

Evaluating the Potential for Platoons of Self-Propelled Autonomous Railcars (SPARCs) to Provide Short-Haul Intermodal Service on Low-Density Rail Corridors

Geordie Roscoe[a], Matthew Parkes[b] and C. Tyler Dick[a].

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[b] *University of Illinois Urbana-Champaign*

United States freight railroads consume in excess of 13 billion litres of diesel fuel yearly. While efforts to improve energy efficiency and reduce emissions have made substantial progress in the past decades, the benefits are relatively incremental and will not be sufficient to realize full decarbonization. Several independent efforts are underway to develop alternative locomotive fuels and propulsion technologies designed to fit within the typical locomotive shell. In addition to these more conventional efforts, multiple start-up companies are working to develop Self-Propelled Autonomous Railcars (SPARCs) that achieve this decarbonization while also shaking up the traditional railroad operating paradigm. SPARC operations with multiple platoon lengths, as well as a control conventional train scenario were simulated on an example corridor. This line is single track with short sidings on inconsistent intervals, which is typical of us branch lines serving few local customers without heavy through traffic. For all traffic levels simulated, SPARCs had a much lower transit time than the conventional trains. Optimal platoon length varied between 15 and 38-vehicles per platoon depending on the traffic demand, well under North American standards of over 100 car trains.

Keywords
Autonomous Trains, SPARC, Self-Propelled Rail, Railway Operations

Session 3.3A: Timetabling V
Submission type: Industrial paper
Presentation type: Oral
Paper ID: [131]

Station capacity assessment with probabilitstic approach: a case for Ringsted station in Denmark

Fabrizio Cerreto

Banedanmark

This study applies a probabilistic method to assess the station capacity utilization, and the fitness of a station track layout to a traffic plan. The reviews of available methods lead to the selection of a method based on traffic plan, track layout, and station routes occupation times. The method's strength is the balance between simplicity of input and completeness of output and factors considered. The application to a Danish case reveals some shortcomings, that were addressed with adapting the method. The definition of desired station capacity utilization, its sensitivity to changes in the traffic plan, and uncertainty interval around the desired level should be addressed with further studies. The case study shows the benefit of shortening blocking sections and reducing the occupation times at stations. This result is shorter blocking times between conflicting station routes and, consequently, a lower capacity utilization by the a given traffic plan. This analysis is suitable for the initial project phases in the infrastructure planning process, for the screening of scenarios to be further investigated.

Keywords
Station capacity, Traffic plan, Probability, Track layout, Capacity utilization

Session 3.2C: Rail governance and economics
Submission type: Research paper
Presentation type: Oral
Paper ID: [132]

Selection of the Optimal Railway Public Services Regarding External Costs and Transport Market Structure

Predrag Jovanović, Miloš Nikolić and Dragana Macura.

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Public service transport is very important for passenger transport, both from a political and an economic point of view. The rail passenger transport is typically not commercially sustainable, although needed for the society's welfare. The domestic rail passenger transport services are usually co-finance by governments throughout the world. However, due to the limited budget for public service obligation (PSO) the selection of rail routes under the PSO contract is the challenge for decision makers. In this paper, the model for the optimal selection of the rail PSOs is developed. The integer linear programming is used to achieve the maximum total benefit of the proposed rail routes based on their benefits (decrease in external costs and Herfindahl-Hirschman Index (HHI) for each route are defined), with the limited budget. The proposed model is used to analyze the rail PSOs selection in a case study of the Serbian rail network.

Keywords
Public Service Obligation, Government, Railway Operator, Integer Linear Programming

Session 1.2A: Railway performance I
Submission type: Research paper
Presentation type: Oral
Paper ID: [134]

Service quality assesment of international rail transport

Jing Shan, Nikola Bešinović and Jörn Schönberger.

TU Dresden

International rail transport plays an important role in the supply chain and has increased over the last decade due to its low carbon footprint. Since launch of Eurasian railway transport in 2011, it has experienced rapid expansion. However, relatively little is known about the service level of Eurasian railway transport and whether it has met supply chain performance requirements. International rail services are not cleary defined and there is less literature on measuring the quality of international rail services. Many studies have addressed rail transport performance assessment but have mainly focused on efficiency and productivity measurements, or at the regional level. This paper harmonizes service performance measurement of supply chains and international rail transport, including key performance parameters of reliability, speed, flexibility, cost and asset efficiency based on the Supply-chain operations reference (SCOR) model and have been tested on Euroasian railway network. Further, service differentiation and priorities rules are introduced to improve the international rail services.

Keywords
Supply chain, International Railway Transport, Rail service quality, Railway Supply Chain

Session 2.3B: Railway signalling and control systems
Submission type: Research paper
Presentation type: Oral
Paper ID: [135]

Analysis of Safe and Effective Next-Generation Rail Signalling Systems using a FTA-SAN Approach

Joelle Aoun[a], Rob M.P. Goverde[a], Roberto Nardone[b], Egidio Quaglietta[a] and Valeria Vittorini[c].

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[c] *University of Naples "Federico II"*

Moving Block (MB) and Virtual Coupling (VC) rail signalling will change current train operation paradigm by migrating vital equipment from trackside to onboard to reduce train separation and maintenance costs. Their actual deployment is however constrained by the industry's need to identify configurations of MB and VC signalling equipment which can effectively guarantee safe train movements even under degraded operational conditions involving component faults. In this paper, we analyse the effectivity of MB and VC in safely supervising train separation under nominal and degraded conditions by using an innovative approach which combines Fault Tree Analysis (FTA) and Stochastic Activity Network (SAN). A FTA model of unsafe train movement is defined for both MB and VC capturing functional interactions and cause-effect relations among the different signalling components. The FTA is then used as a basis to apportion signalling component failure rates needed to feed the SAN model. Effective MB and VC train supervision is analysed by means of SAN-based simulations in the specific scenario of an error in the Train Position Reporting (TPR) for five rail market segments featuring different traffic characteristics, namely high-speed, mainline, regional, urban and freight. Results show that the overall approach can support infrastructure managers, railway undertakings, and rail system suppliers in investigating effectiveness of MB and VC in safely supervising train movements in scenarios involving different types of degraded conditions and failure events. The proposed method can hence support the railway industry in identifying effective and safe design configurations of next-generation rail signalling systems.

Keywords
Moving Block, Virtual Coupling, Safety, Performance, Stochastic Activity Network

Session 2.2B: Railway alignment and network design
Submission type: Research paper
Presentation type: Oral
Paper ID: [136]

Recreation of horizontal alignments with numerical optimization

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and Miguel Ernesto Vázquez-Méndez.

University of Santiago de Compostela

In this paper a new method for recreating horizontal alignments of existing railway lines by using numerical optimization is presented. Based on a previously defined geometrical model of a horizontal alignment consisting on the combination of tangents, circular curves and transitional curves, two different constrained optimization problems are formulated. The objective in both problems is obtaining an optimized recreated alignment located as close as possible to an existing one defined by the coordinates of a set of points belonging to its centerline, taking into account some technical constraints. The first problem considers only the information of this set of points for searching the optimal alignment while the second problem also includes additional data about the geometry of the existing alignment in the optimization process. The proposed method consists on two stages in which both problems are consecutively solved by numerical techniques in order to obtain an optimal recreated alignment. In order to show its usefulness, this method is applied to a case study of a railway line section located at Parga (Spain) in which the geometry of its horizontal alignment is successfully recovered.

Keywords
Recreated horizontal alignment, Geometrical model, Constrained optimization problem, Numerical resolution

Session 3.3C: Railway traffic management and rescheduling II
Submission type: Research paper
Presentation type: Oral
Paper ID: [137]

Dispatching Strategy for Cross-bureau and Cross-line Trains in Railway Network Operations

Xiaoyu Hou, Xiaojie Luan, Zhengwen Liao, Jianrui Miao, Lingyun Meng and Pu Zhang.

Beijing Jiaotong University

With the high-speed lines formed into a network and the increase of train speed, train dispatching is faced with a more and more complex decision-making situation. In real train operations, the sequences and the hand-over times of cross-line trains and cross-bureau trains can affect the running of those trains on the connected lines, as well as the intensity and efficiency of dispatching tasks. Keeping the planned sequence or the planned hand-over times for cross-line and cross-bureau trains are practically and particularly considered by train dispatchers in China. In this paper, two different dispatching strategies are considered for cross-line and cross-bureau trains. Taking the minimization of the total train delay as the objective, a train dispatching model is constructed, with partially restricted train sequences and hand-over times (for cross-line and cross-bureau trains). To quickly obtain a solution with good quality, this paper proposes an improved genetic algorithm to solve the model. We perform experiments to comparatively examine the two proposed dispatching strategies, showing the benefits and costs of keeping the train sequences and hand-over times. It is demonstrated that the proposed improved genetic algorithm can obtain solutions much more quickly than the standard commercial solver CPLEX, with a little sacrifice of solution quality.

Keywords
Train rescheduling, Dispatching strategy, Genetic algorithm, Decision-making support

Session 1.2B: Railway safety analysis and risk assessment
Submission type: Research paper
Presentation type: Oral
Paper ID: [138]

Probabilistic Modelling of Optimal Placement Strategies of Hazardous Materials Railcars in Freight Trains

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Hazmat cars are subject to differing probabilities of being involved in a derailment depending on their positioning in trains. This effect is particularly important in long-freight-train characteristic of North American operation. For decades there has been discussion about whether operating practices and regulations should account for this to reduce the chance that hazmat cars will be involved if a train derails. This paper presents a position-dependent, railcar-based method to analyze derailment probability of hazmat cars and identify optimal placement strategies that minimize the expected number of hazmat cars derailed. The method considers derailment probabilities of each hazmat car at each location in a train and investigates the optimal placement of hazmat cars given train makeup, train derailment speed, and the percentage of hazmat cars. A case study based on realistic train configuration and operational conditions is presented that demonstrates the method and a sensitivity analysis is presented that explores the effect of key factors on the placement strategies. The research indicates that there is no single placement strategy that minimizes the hazmat car derailment probability under the variety of characteristics typical of North American freight train operation. This result has implications for rail hazmat transportation safety, operations, efficiency and regulatory policy. This research advances our understanding of the effect of hazmat car placement on operating safety and risk and enables development of holistic quantitative models to address the trade-off between hazmat train operating safety and efficiency that accounts for both mainline derailment severity and yard activities related to train make-up.

Keywords
Railway safety, Derailment, Hazardous materials, Dangerous goods, Train configuration, Risk analysis

Session 1.1B: Emerging railway technologies
Submission type: Research paper
Presentation type: Oral
Paper ID: [139]

Vehicle-to-Grid Concept for Hydrogen Fuel Cell Hybrid-Electric Regional Trains

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Hydrogen fuel cell multiple unit vehicles are acquiring a central role in the transition process towards carbon neutral trains operation in non-electrified regional railway networks. In addition to their primary role as a transport mean, these vehicles offer significant potential for applications in innovative concepts such as smart grids. Compared to the pure electric propulsion systems, fuel cell technology allows for cogeneration processes by recovering generated heat in addition to the provision of the electrical power. This paper presents the analysis of fuel cell hybrid-electric multiple unit vehicle employed in regional railway transport during regular service, and in vehicle-to-grid application during the off-service hours, where it provides the electrical and thermal energy for stationary consumers in terminal stations. The system dynamics are modelled using a backward-looking quasi-static simulation approach, with implemented real-time optimization-based control strategy for managing the power flows between different components. In a case study of selected vehicle and railway services in the Netherlands, the fuel cell system showed average hydrogen consumption of 0.4 kg/km, with the overall electrical efficiency of 38.89%. In vehicle-to-grid scenario, the system satisfied complete stationary power demand, and provided about 327 kWh of thermal energy during two-hours operation, reaching overall cogeneration efficiency of 66.81%.

Keywords
Regional railways, Hydrogen, Fuel cell hybrid-electric systems, Vehicle-to-grid

Session 3.2C: Rail governance and economics
Submission type: Research paper
Presentation type: Oral
Paper ID: [140]

Optimal Allocation of Waste Transfer Facilities for Infrastructure Manager

Nikola Ristić[a], Pavle Kecman[b] and Predrag Jovanović[c].

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[c] *University of Belgrade, Faculty of Transport and Traffic Engineering*

Railway systems all over the world follow the demographic and economic development of certain areas based on the principle of "circular cumulative causality", which causes that the generated waste which should be treated in a proper way. The primary goal of the paper is the definition of a mathematical model for the optimization of transport flows in order to contribute to the planning and organizational activation of the spatial potential along the railway corridor, with minimization of transport costs and negative impacts on the environment. In the paper we developed the mixed integer linear programming mathematical model, which usage would enable cost reduction, more efficient resource management, recycling building capacity and a closed cycle of material circulation. The proposed model proposes the location of new collection points (hubs). As a final result, the proposal of a new applicable and methodological approach to waste management research is given in the paper, which could be used as a basis for further development with an aim secure more practical usage of the defined model.

Keywords
Waste Management, Railway Infrastructure, Mixed-Integer Linear Programming, Optimization

Session 2.2C: Rail yard operation and design
Submission type: Research paper
Presentation type: Oral
Paper ID: [141]

Freight train scheduling for industrial lines with multiple Railway Undertakings

Daniel Haalboom and Nikola Bešinović.

TU Dresden

With the liberalisation of the rail freight marked, the number of railway undertakings is increasing. Their offered services converge in yards leading up to terminals. Here, limited capacity lead to bottlenecks, reducing resource utilization of railway undertakings. Supplementary services by an independent local railway undertaking can improve capacity utilization and decrease the time engines of mainline engines spend within the considered network. In this paper, we propose a resource scheduling model for freight trains in yards to minimize the time engines of a railway undertaking spend in the yard. The model considers operations to be performed by the same resource and takes particular functions of a process within the operation chain into account. The results show that the potential savings per employed local engine are highly dependent on the overlapping of inbound and outbound blocks within the network and on the degree of local railway undertaking involvement.

Keywords
Freight Rail, Railway Undertakings, Industrial Railway, Production Schedule, Optimization

Session 3.2A: Timetabling IV
Submission type: Research paper
Presentation type: Oral
Paper ID: [142]

Periodic train timetable expansion: An integrated model of multi-period train service selection and rolling stock circulation with time-varying passenger demand

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[b] *Delft University of Technology*

The periodic train timetable is one of the most widely used train timetables in passenger railway systems worldwide. However, how to expand well-coordinated daily train services from a single-period timetable pattern is rarely studied. This paper develops a multi-objective mixed integer programming model to solve the periodic train timetable expansion problem, aiming to optimize passenger waiting time and rolling stock operation costs. In our model, the time-varying passenger assignment, train service selection, and rolling stock circulation planning are integrated. Moreover, the rolling stock circulation is considered with a flexible composition mode for efficiency. An ε-constraint method is introduced to explore the Pareto frontier for the multi-objective model and analyze the trade-offs between the service quality and operating cost. The model and analyzing theorem are validated via the real-world case Guangzhou-Shenzhen Intercity Railway transit system.

Keywords
Periodic train timetable, Rolling stock circulation, Flexible train composition, Time-varying passenger demand, Integrated optimization

Session 2.4C: Rail freight transport II
Submission type: Industrial paper
Presentation type: Oral
Paper ID: [145]

Strategies for the Improvement of Rail Freight Transport Between the Republic of Turkey and Republic of Serbia: A Case Study Using A'WOT Model

Vladan Nikolic

LogAgent LLC

The importance of strategic management is increasing as the business environment becomes more and more unstable. Strategic planning in rail transport has also gained importance as this industry, known for having changed relatively little since its inception, adopted principles of open market economy and implemented measures aimed at deregulation and liberalization. Steadily growing freight volumes carried from Turkey to the region of Western Balkans, as well as recently launched Eurasia routes going through Turkey provide another business opportunity for the rail and logistics companies, but present a great challenge too. In this paper, SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis is used together with Analytic Hierarchy Process (AHP) to prioritize factors included in SWOT matrix and to propose a number of strategies for the improvement of rail freight transport between Turkey and Serbia. A hybrid method, known as A'WOT, circumvents certain limitations of the SWOT analysis as a basic tool, primarily those related to obtaining quantitative information on the priorities of the evaluated factors.The results obtained are suitable for further research and application.

Keywords
Rail freight transport, Strategic management, Analytic hierarchy process, SWOT analysis

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The International Association of Railway Operations Research (IAROR) was founded in 2005 and has currently more than 400 members. IAROR combines the expertise of academic and professional railway research with the aim of enhancing the quality of service for railway passengers and customers, improving the effectiveness and efficiency of capacity management, timetabling, traffic management and ensuring the safety of railway operations. IAROR stimulates innovative theoretical approaches, high-tech concepts, new technological developments and dynamic decision support systems that contribute to a higher flexibility, performance and punctuality of trains operating on single or dedicated lines and in heterogeneous networks. IAROR contributes to the development of new international standards for railway capacity and traffic management by integration of the state-of-the-art from different scientific disciplines as engineering, mathematics, physics, economics and computer science. IAROR is a Network of Excellence in the field of railway operations research.

University of Belgrade – The Faculty of Transport and Traffic Engineering

University of Belgrade is one of the oldest and largest universities in South-East Europe. Founded in 1808, it consists of 31 faculties, 11 research institutes, 13 university centers and the university library. It provides education in sciences and mathematics, technology and engineering sciences, medical sciences, social sciences and humanities, with about 380 study programs, 95.000 students and 5.000 academic and research staff. During the two centuries of its existence, the University of Belgrade has served its people, and its former students and teachers have greatly contributed to the development of cultural, scientific, educational, political and economic life of Serbia.

The Faculty of Transport and Traffic Engineering represents the oldest educational and research institution in the broad area of transportation in Serbia, founded in 1950. As a part of University of Belgrade, the faculty provides accredited study programs at undergraduate, master and doctoral academic levels in the field of technology and engineering sciences covering areas of traffic, transport, logistics and telecommunications. Over the past seventy years, the Faculty has educated more than 10,000 graduates including about 200 doctors of technical sciences. Today, the Faculty has about 2000 students enrolled in nine undergraduate and eleven master majors, and one comprehensive doctoral study program.

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Stadler employs around 13 500 people worldwide and offers a comprehensive range of products in the railway and commuter rail segments: high-speed trains, EE trains, regional and suburban trains, subway trains, tram trains and trams. In addition, the company manufactures locomotives and passenger carriages. We are also the world's leading manufacturer of rack-and-pinion rail vehicles.
Stadler builds a number of trains with alternative drives: rechargeable batteries, hybrid, hydrogen. As a result, Stadler's model series such as FLIRT and WINK can be designed as purely battery-operated vehicles or as hybrid vehicles. In combination with the light-weight aluminium composite construction of the car bodies and Stadler's automation solutions, these innovative drive concepts help to increase the environmental performance of railway transport even further.
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TRENOlab is an independent, employee-owned consulting and software development company. Our mission is to provide high quality railway consulting services and to continually improve our TRENO suite of railway timetable analysis software.

Our team consists of transport engineers and software developers. Some of us have been working on railway timetable analysis and software development for over ten years, others are just beginning their careers. But, we all share a deep passion for our work because we believe railways are a highly sustainable and attractive form of transport.

This passion drives us to develop innovative solutions for helping railways operate at their very best. We're curious and unafraid of examining new approaches. We're happy to develop customised software to solve specific problems. Our goal is to make the world a little better by helping railways optimise their operations, investment planning and customer service.

Our founders began developing railway software over ten years ago during their university studies and since then have continuously improved the software, adding new features, creating enhanced user interfaces and improving functionality. What began as a simple tool to solve specific problems has evolved into a fully integrated suite of railway operational planning, analysis and simulation software.

The Treno suite of railway operational planning software consists of:

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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.

msc MEDITERRANEAN SHIPPING COMPANY

MSC Mediterranean Shipping Company, headquartered in Geneva, Switzerland, is a global leader in transportation and logistics, privately owned and founded in 1970 by Gianluigi Aponte. As one of the world's leading container shipping lines, MSC has 675 offices across 155 countries worldwide with over 150,000 employees. With access to an integrated network of road, rail and sea transport resources which stretches across the globe, the company prides itself on delivering global service with local knowledge. MSC's shipping line sails on more than 260 trade routes, calling at over 520 ports.
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SAOBRAĆAJNI INSTITUT CIP is a leading design and engineering company in Serbia and Balkan region in the field of research, planning, designing, technology, technical verification and supervision of works in the traffic and transport, civil engineering and construction, architecture, geology, geodesy, geotechnical engineering, electrical engineering and mechanical engineering sectors.
CIP has a wide range of company's big licenses issued by relevant authorities of the Republic of Serbia. In its business operations, CIP consistently applies an integrated management system and has quality management certificates in accordance with ISO standards.
Our high-level multidisciplinary teams are trained and equipped for implementation of the most complex designs, with an imperative to find the most rational solutions for our clients. We take care of individuals and their progress, promote and respect experts of various profiles because we believe that an interdisciplinary approach brings great ideas, new energy and the best solutions.

PLANET SOFT is a regional ICT group that operates on the territory of the Adriatic region from its companies in Belgrade, Vienna, Banja Luka and Podgorica. The primary focus of the company are solutions that improve, optimize, and automate business processes, with the aim of raising the level of efficiency and effectiveness of our clients. A special focus is dedicated to traffic and transportation, and we employ traffic engineers, electrical engineers, and software engineers. In the field of traffic, we deliver solutions and services for traffic management, planning and simulations of timetables, traffic infrastructure monitoring. The long-term experience of experts employed at Planet Soft and partnerships with global software and hardware leaders are proof of our commitment to our clients. Constant investment in the knowledge and professional skills of employees, following trends and adopting new technologies in the business environment is the path we have chosen.

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Dragon Maritime SEE is the general representative of the largest Chinese shipping company "COSCO Shipping Lines Co." for the territory of Southeast Europe. We provide to our clients services of maritime transport (container, general and bulk cargo), truck transport of goods, rail transport of goods, air transport of goods, forwarding, storage, customs clearance and other services in the transport of goods.
The company was founded in 2005 in Belgrade, and has offices in Rijeka, Croatia (2009), Koper, Slovenia (2012) and Sarajevo, BiH (2018).
Since 2017, it has been offering its clients a unique intermodal service "Land-Sea Express" that connects the Far East and Serbia and is closely connected with the Chinese "Belt and Road" Initiative. As part of the aforementioned service, clients have the option of choosing between two different transport routes, the first which involves a direct rail connection between the port of Piraeus and Belgrade, and the second, which connects Belgrade with the ports of Piraeus and Rijeka through the PRS service (Piraeus Rijeka Express) and further rail connections.

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Nelt Group is one of the most successful Western Balkans business systems in the field of logistics and distribution of FMCG, tobacco, pharmaceuticals and beauty products. As an international groupation it employs 5,500 people in 12 European and African markets.
Leader position and accomplishments achieved during 30 years in business are the results of constant investment in the development of services, new technologies, education and employees growth. By relying on the principles of responsible and sustainable business, Nelt Group grew by entering new markets and expanding the portfolio of products it distributes and services it provides in logistics. Also, the focus is on education projects in local community, which is why Nelt Group is recognized as its important member.

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Egis is an international player active in the consulting, construction engineering and mobility service sectors. We design and operate intelligent infrastructure and buildings capable of responding to the climate emergency and helping to achieve more balanced, sustainable and resilient territorial development.
With operations in 120 countries, Egis places the expertise of its 16,200 employees at the disposal of its clients and develops cutting-edge innovation accessible to all projects. Through its wide-ranging fields of activity, Egis is a central player in the collective organization of society and the living environment of citizens all over the world.
Egis d.o.o. Beograd was established in 2012 in Serbia to provide local expertise in transport, water, sewerage, environment and urban development engineering sectors. Located in Serbia, company is involved in numerous projects in the Western Balkans region: Serbia, Bosnia and Herzegovina, Croatia, Montenegro and Macedonia, providing services in various sectors, such as roads and motorways, railways, aviation and water.

LogAgent is a dynamic logistics company aimed at providing comprehensive, sustainable and knowledge-based transport and logistics services tailored for a variety of customers, from startups to Fortune Global 500 corporations. For almost a decade, we have been offering rail, road, air and sea transport, warehousing, distribution and customs services, as well as complete logistics solutions for supply chain management. Through our consulting services, we strive to bring the latest industry expertise closer to our customers. Together with our partners worldwide, our team of experienced professionals and promising young graduates works 24/7 to provide fast and reliable services which add value and fuel our customers' success. We build a reputation based on commitment, professionalism and integrity. This is LogAgent way!

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Source: Aleksandar Matić (TOB)

About Belgrade

Belgrade, the capital of the Republic of Serbia, is located in South-East Europe, at the beautiful confluence of the Sava and the Danube rivers. After Istanbul and Athens**,** Belgrade is the third largest city in South-eastern Europe. Belgrade has around 1.6 million residents and presents the financial and economy center of Serbia. In the field of traffic and transport, it is a city of great importance for South-East Europe, as a road and railway center, as a port for river and air traffic, and as a telecommunication center.

Belgrade's history lasts full 7,000 years. Many cultures and tribes left their mark in its long and turbulent history: Thraco-Dacians, Celts, Romans, Byzantines, Slavs, Ottomans, Austro-Hungarians, have all shaped Belgrade one of the most diverse and interesting cities of South-East Europe. The official language is Serbian, while visitors from abroad can use English to communicate.

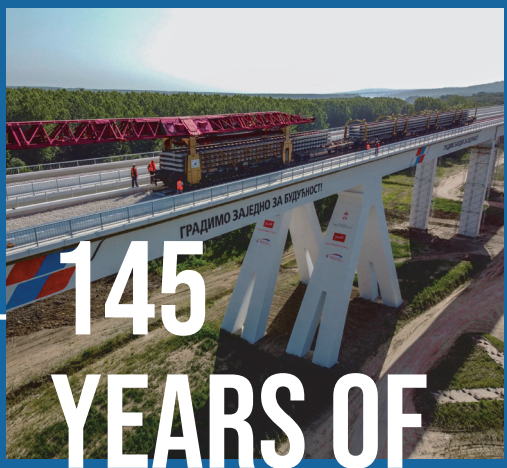
Belgrade is the capital of Serbian culture, education and science with many institutions of national importance in the field of science and art. There is the Serbian Academy

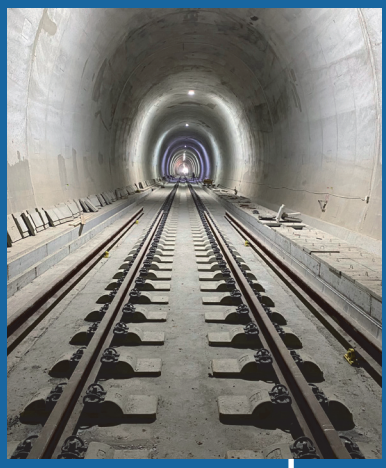
Source: Aleksandar Matić (TOB)

of Sciences and Arts, established in 1886 as the Serbian Royal Academy; the National Library of Serbia, established in 1832; the National Museum, established in 1841 and the National Theatre, established in 1869. The city is also the seat of the Belgrade University, founded in 1808 as the Great School, and the seat of the University of Art. Throughout the year Belgrade offers numerous concerts, festivals and cultural events. Some of the best-known festivals and events are: International Film Festival – FEST, Belgrade Summer Festival – BELEF, Belgrade Music Festivities – BEMUS and Belgrade International Theatre Festival – BITEF.

The city is home to Serbia's two biggest and most successful sport clubs, Red Star Belgrade and Partizan Belgrade. Red Star won the UEFA Champions League (European Cup) in football (1991), and Partizan won the EuroLeague in basketball (1992). Besides that, Belgrade has been host to many important sport events in its history. Some of them include: European Football Cup Final (1973), European Football Championship (1976), EuroBasket (2005), Summer Universiade (2009), European Athletics Indoor Championships (2017), EuroLeague Final Four (2018). In 2022, Belgrade is host to EuroLeague Final Four in basketball and World Athletics Indoor Championships.

Belgrade has a sister city or twin city agreement established with Coventry (UK), Chicago (USA), Ljubljana (Slovenia), Skopje (North Macedonia), Shanghai (China) and Banja Luka (Bosnia and Herzegovina), as well as an extensive list of cultural relationships with other cities around the world.





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SAOBRAĆAJNI INSTITUT CIP d.o.o is a leading design and engineering company in Serbia and Balkan region in the field of research, planning, designing, technology, technical verification and supervision of works in the traffic and transport, civil engineering and construction, architecture, geology, geodesy, geotechnical engineering, electrical engineering and mechanical engineering sectors.

CIP has a wide range of company's big licenses issued by relevant authorities of the Republic of Serbia. In its business operations, CIP consistently applies an integrated management system and has quality management certificates in accordance with ISO standards.

Our high-level multidisciplinary teams are trained and equipped for implementation of the most complex designs, with an imperative to find the most rational solutions for our clients. We take care of individuals and their progress, promote and respect experts of various profiles because we believe that an interdisciplinary approach brings great ideas, new energy and the best solutions

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