BOOK OF ABSTRACTS

LOGMS 2024

Digital Waves in Logistics and Maritime Systems: Sailing Towards Efficiency

August 26- 29, 2024

hosted by the University of Hamburg

Edmund-Siemers-Allee 1, ESA East, Hamburg, Germany.

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Organizing Institution

Proceedings to appear in

Conference Chairs

Stefan Voß, *University of Hamburg, Hamburg, Germany*

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Preface

The public has become increasingly aware of the critical role of reliable and efficient logistics, especially due to the impacts of the COVID-19 pandemic and the Russian war against the Ukraine. Events like the Suez Canal blockage or Houthi attacks further highlighted the vulnerability of logistics processes and their significant economic repercussions. Despite trends toward de-globalization and reshoring, the focus must also be on creating resilient logistics structures alongside efficiency and cost management. Efficient logistics has become essential for the economic success of companies, particularly in manufacturing and retail.

In recent years, there have been substantial advancements in logistics, as well as information and communication technologies. Innovations include the development of sophisticated algorithms, increased automation in transport and warehousing (including autonomous systems), applications of artificial intelligence, new materials, manufacturing processes, and advances in communication technology. These developments necessitate an integrated approach that combines logistical functions, quantitative solutions, decision support methods, and effective information management.

Additionally, the role of environmental sustainability in logistics has become increasingly important. Companies are now prioritizing eco-friendly practices to reduce their carbon footprint and promote sustainability. This includes optimizing routes for fuel efficiency, investing in green technologies, and implementing sustainable supply chain practices. The integration of environmental considerations into logistics strategies not only helps in compliance with regulations but also enhances the corporate reputation and contributes to long-term economic viability. Emphasizing sustainability in logistics ensures that businesses can meet current demands without compromising the ability of future generations to meet their own needs.

The primary goal of the *International Conference on Logistics and Maritime Systems* (LOGMS), held globally for the past 14 years, is to address important issues and drive advancements forward. Founded on two previous conferences (International Conference on Intelligent Logistics Systems 2005-2009; International Symposium on Maritime Logistics and Supply Chain Systems

2009), the conference was held 2010 in Busan (South Korea), 2012 in Bremen (Germany), 2013 in Singapore, 2014 in Rotterdam (The Netherlands), 2015 in Hong Kong, 2016 in Sydney (Australia), 2017 in Bergen (Norway), 2018 in Guangzhou (China), 2019 in Zhoushan (China), and 2023 in Busan (South Korea). In August 2024, the 12th LOGMS conference took place in Hamburg (Germany), also known as "the gate to the world", due to its over 800-year history as a port city and its status as one of the busiest ports in Europe.

We also aimed to provide a forum for scholars and practitioners to facilitate an intensive exchange of knowledge on recent developments in the field of logistics and maritime systems. Presentations and discussions of current research results as well as developments in various areas of logistics and maritime systems were at the foreground.

This book of abstracs includes the paper abstracts and extended abstracts that were accepted after a single-blind peer review process, each evaluated by at least two reviewers, and subsequently presented at the conference. This year, we recognized the large number of extended abstracts and papers applying means of artificial intelligence in the form of optimization methods and machine learning as well as a huge focus on digitalization and smart technologies, addressing - in one way or another - all aforementioned challenges and advancements in maritime logistics.

The editors thank the authors for their submissions as well as the program committee and the reviewers for their helpful support and important feedback which have made a significant contribution to the realization of this book. Finally, we would like to express our thanks to Julia Bachale for her comprehensive support and assistance during the preparation of the conference and also the manuscript. We trust that the present book of abstracts and the upcoming LNCS Proceedings support the more important advances within logistics and maritime systems and inspire all participants and readers to further research activities.

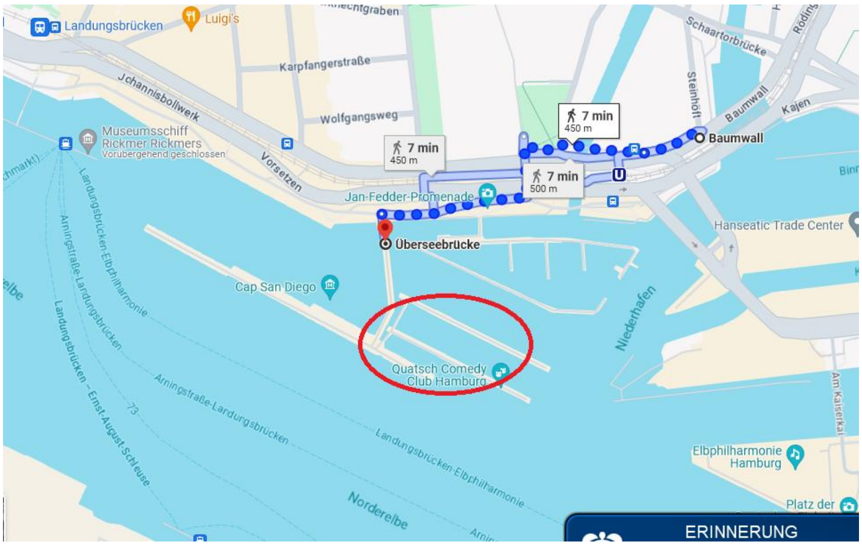
Leonard Heilig
Stefan Voß

Conference Events

Conference Dinner 28.08.2024, 18:30h, MS Hanseatic, Überseebrücke

For finding your way to our Conference Dinner venue, the MS Hanseatic, we recommend to install the HVV app on your phone:

In case you cannot install the app, please use the following description: From the University main building, please walk to Dammtor/Stephansplatz and take the U1 to station Rathaus. Please switch to U3 until reaching station Baumwall. From there, please walk down to the Überseebrücke. The MS Hanseatic will be moored within the indicated area on the below-shown map.



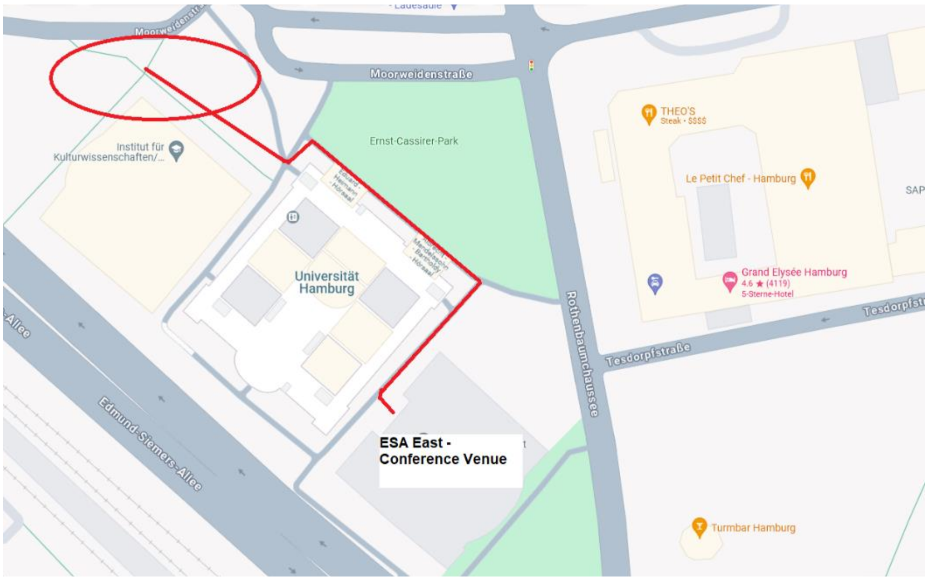
This is what the MS Hanseatic looks like:

Please be aware that Hamburg traffic (even concerning PT) is often prone to delays. We kindly ask you to arrive at the venue at 18:30h the latest in order for us to cast off on time.

The conference dinner tour will last about three hours; the ship will moor at about the same area where it casts off.

Excursion to Eurogate Container Terminal, 29.08.2024, 9:00 h

The busses for the excursion to Eurogate Container Terminal will park behind the ESA Main Building in the indicated area:



The excursion participants can access the busses at 9:00 h in the indicated area and will return to this spot by bus after the excursion at around 13:00 h. Participants who attend the visit to the Nautical Center will return at about 14:30 h.

Conference Program

Time	26.08.2024
16:00-18:00	Registration at ESA East, Room 221
18:00- approx. 20:00	Welcome Reception

Time	27.08.2024		
8:30-9:30	**Registration II**		
9:30-10:00	Room 221 **Welcome Session** *Chair: Stefan Voß*		
10:00-11:30	**Session 1 .1, Room 121** Smart Ports *Chair: Rommert Dekker*	**Session 1 .2, Room 122** Intermodal Transport *Chair: Christian Bierwirth*	**Session 1 .3, Room 123** Container Stacking & Storage *Chair: René de Koster*
	Data Platforms in the Maritime Domain: Challenges and Opportunities *Anisa Rizvanolli and Olaf Rendel*	Competitive Service Network Design and Pricing for Intermodal Transport *Adrien Nicolet and Bilge Atasoy*	Q-Learning for Outbound Container Stacking at Container Terminals *Aaron Lim, Seokchan Lee, Jeongyoon Hong, Younghoo Noh, Sung Won Cho and Wonhee Lee*
	Drone-Based Identification of Containers and Semi-Trailers in Inland Ports *Jana*	Route Planning with Heterogeneous Environmental Preferences of Shippers	Enhancing Port Efficiency: A Simulation-Based Study of Container Reshuffling

	Teegen, André Kelm, Ole Grasse, Maris Hillemann, Emre Gülsoylu and Simone Frintrop	*Justin Wittig and Christian Bierwirth*	in Container Yards *Mengya Liu, Xin Chu, Zexin Lin and Haobin Li*
	Addressing Challenges in Creating Traffic Profiles for Transshipment Hubs in Seaports *Shubhangi Gupta, Marvin Kastner, João Vieira and Carlos Jahn*	AI-based Delay Estimation for Freight Trains *Chhandosee Bhattacharya, Anisa Rizvanolli and Ole John*	Determining the Throughput Capacity of Mixed-Load Multi-Deep Storage and Retrieval Systems *René De Koster and Timo Lehmann*
11:30-12:00	Coffee Break, Room 221		
12:00-13:30	**Session 2 .1, Room 121** Smart Terminals *Chair: Leonard Heilig*	**Session 2 .2, Room 122** Maritime Shipping *Chair: Branislav Dragović*	**Session 2 .3, Room 123** Berth Planning *Chair: Rob Zuidwijk*
	TwinSim: Development of a Digital Twin for Container Terminals *Paul Kokot and Leonard Heilig*	An Insight of COVID-19-Related Literature in Maritime Transport *Branislav Dragović, Nenad Zrnic and Andro Dragović*	Dynamic Berth Allocation Policies in the Deep-Sea Terminals *Rob Zuidwijk, Pieter van den Berg, Orkun Tunay and Debjit Roy*
	Using Activity-Based Formalism to Analyse a Container Terminal Model in Flex-Term	Forecasting the Baltic Dry Index Using Machine Learning	Optimizing Vessel Scheduling and Berth Allocation in Constrained Mari-

	Changying Shao, Haobin Li, Tianhao Chen and Zexin Lin	*Tim Seemann, Pierre Bouchard and Stefan Voß*	time Environments: A Metaheuristic Approach *Christian Bierwirth, Robert Burdett and Paul Corry*
	Performance Estimation of Twin Cranes in Container Terminals *Ningning Song, Kap Hwan Kim and Xuehao Feng*	Strategic Fleet Planning in Collaborative Logistics in the Offshore Oil and Gas Industry *Andreas Breivik Ormevik and Kjetil Fagerholt*	Risk or Slack – How to Tackle Uncertainty in Berth Allocation Planning *Lorenz Kolley and Kathrin Fischer*
13:30-14:30	Lunch Break, Room 221		

14:30-16:00	**Session 3.1, Room 121** Port Digitalization and Automation *Chair: Ikyeong Moon*	**Session 3.2, Room 122** Manufacturing, E-Commerce and Last-Mile Delivery *Chair: Lijun Ma*
	A Dynamic Pickup-and-Delivery Problem with recharging for Autonomous Delivery Robots in an Airport Terminal *Joonhwa Jeong and Ilkyeong Moon*	Hybrid Flow Shop Scheduling with Workforce Assignment for Additive Manufacturing *Benedikt Zipfel and Nadine Schiebold*
	Pricing and Empty Container Repositioning Strategy for Container Sharing System *Junseok Park and Ilkyeong Moon*	Sequential Sponsored-Products and Off-Amazon Advertising Optimization for Etailers *Yina Ning, Yangyang Xie, Houmin Yan and Lijun Ma*

	Development of a Novel QC Work Congestion Index to Enhance Accuracy in Predicting Ship Operation Time *Daesan Park, Taeeon Noh, Yohan Koo, Hyeonjik Lee and Hyerim Bae*	Last-Mile Delivery Route Optimization Considering Collection of Reusable Bags *Sangjun Yoon, Gwang Kim and Youngchul Shin*
16:00-16:30	Coffee Break, Room 221	
16:30-18:00	**Session 4.1, Room 121** Sustainable Maritime Logistics *Chair: Kap-Hwan Kim*	**Session 4.2, Room 122** Waterway Transportation *Chair: Frank Meisel*
	A Semi-supervised Learning Imputation Model for Automatic Identification System Data *Jaehyeon Heo, Dohee Kim, Sekil Park, Sunghyun Sim and Hyerim Bae*	A Graph Neural Network Approach for the Waterway Ship Scheduling Problem *Peter Wenzel, Nahom Tsehaie, Raka Jovanovic and Frederik Schulte*
	Spatial-Temporal Analysis of Ship Collision Risk *Suhyeon Jo, Dohee Kim, Sekil Park, Sunghyun Sim and Hyerim Bae*	Multi-Period Containerized Battery Swapping Station Location Planning for Inland Waterway Transportation *Virgilio Ma Jr Ramos and Bilge Atasoy*
	Long-Term Forecasting of Pollutant Emissions in the Arctic Ocean Based on Cross-Dimensional Dependency Network using Arctic Ship Traffic Data *Sunghyun Sim, Younghwi Kim*	A Stochastic Optimization Model for Tramp Scheduling with Many-to-Many Matching and Speed Optimization *Liangqi Cheng*

Time	**28.08.2024**
8:00-9:00	**Registration III**

9:00-10:00	Room 221 **Keynote Yvo Saanen:** Digitization to Enable Sustainable Supply Chains *Chair: Leonard Heilig*	
10:00-10:30	Coffee Break, Room 221	
10:30-12:00	**Session 5.1, Room 121** Green Innovations in Smart Port Logistics: Future Directions *Chair: Eon-Kyung Lee*	**Session 5.2, Room 122** Vessel Planning *Chair: Dario Pacino*
	A Hybrid Testing Approach to Secure the Smooth Go-Live of Automated Container Terminals *Holger Schuett*	The Economic Value and Environmental Benefits of Accurately Predicting Arrival Times in International Shipping *Thalis Zis*
	AI-Enhanced Smart Maritime Logistics: Data-Driven Innovations at South Korean Ports *Hyerim Bae*	Stowage Planning with Hybrid Slots, Hazardous Cargo and Stability Limits *Magnus Levinsen, Oliver Thomsen, Dario Pacino and Line Reinhardt*
	New Fuels and their Emissions in the Maritime Industry – Considerations for Sustainable Port Logistics *Kang-Ki Lee*	Attribute Dynamics and Machine Learning in Berth Time Prediction Developing a Selection Framework for Algorithms Based on Time-Variant Data Availability and Vessel Characteristics *Pierre Bouchard, Stefan Voß and Leonard Heilig*
	Innovative OSS Terminal Concept for Efficient Handling of Mega Container Ships	Predicting Ferry Delays Using Machine Learning and Open Data *Malek Sarhani and Mohamed El Amrani*

	Eon-Kyung Lee and JungJoon Bae	
	+ 30 Min Panel Discussion with Kap-Hwan Kim	
12:00-13:00	Lunch Break, Room 221	
13:00-14:30	**Session 6.1, Room 121** Resilient Operations *Chair: Philip Cammin*	**Session 6.2, Room 122** Smart Terminals II *Chair: Hans-Dietrich Haasis*
	Envision: An AI-Driven Wireless Sensing Technology for Cargo Ship Fire Detection *Junye Li, Aryan Sharma, Yirui Deng, Deepak Mishra, Hiran Wijetilaka and Aruna Seneviratne*	Berth Allocation with Integrated Cold Ironing at Maritime Container Terminals: Mathematical Modelling and a Matheuristic Approach *Abtin Nourmohammadzadeh and Stefan Voß*
	Optimizing Maintenance Scheduling Considering Predictive Maintenance Inaccuracy *Jingjing Yu and Philip Cammin*	A Bilevel Model for Locating Intermodal Container Terminals Using the Entropy Maximization Approach *Jiajie Zhang, Yun Hui Lin, Ek Peng Chew and Kok Choon Tan*
	Improving Safety of Navigation and Sustainability of Shipping through Innovative Autonomous Shipping Technologies in Pacific Asia: A Case Study of Thailand *Chackrit Duangphastra*	The Container Assignment Model: An Efficient Three-Stage Solution Method *Michael Bell, Veronica Schulz, Shengda Zhu, Jyotirmoyee Bhattacharjya and Glenn Geers*
14:30-15:00	Coffee Break, Room 221	
15:00-16:00	**Session 7.1, Room 121** Smart Ports II *Chair: Ding Yi*	**Session 7.2, Room 122**

		Environmental Sustainability *Chair: Haobin Li*
	Metaheuristic Approaches for the Straddle Carrier Dispatching Problem *Ahmet Cürebal, Nina Radojičić, Leonard Heilig and Stefan Voß*	Optimizing Maritime Logistics for Ocean Alkalinity Enhancement *Martine Lindland, Emmiche Advocaat Wigand, Kjetil Fagerholt, Frank Meisel and Lisa Herlicka*
	Machine Learning-based Transport Time Prediction in Container Terminals *Julian Neugebauer, Leonard Heilig and Stefan Voß*	Employing System Archetypes to Facilitate Decision-Making in the Transition to Alternative Marine Fuels at the Port of Singapore *Hongdan Chen, Vedpal Arya, Haobin Li and Yanan Li*
16:10-17:30	Room 221 **Keynote Jan Hoffmann:** Digital Waves in Logistics and Maritime Systems: Sailing Towards Efficiency *Chair: Stefan Voß* and Closing Ceremony	
19:00-22:00	Conference Dinner aboard the MS Hanseatic (a detailed description for the location will be provided in the conference package)	

Time	29.08.2024
9:00	Start excursion to Eurogate Container Terminal
Approx. 13:00	Return from the excursion

Book of Abstracts

Welcome Ceremony

Tuesday, 27.08.2024, 9:30-10:00 h, Room 221

Chair: Stefan Voß

Smart Ports

Tuesday, 27.08.2024, 10:00-11:30, Room 121

Chair: Rommert Dekker

Data Platforms in the Maritime Domain: Challenges and Opportunities:
Anisa Rizvanolli, Olaf Rendel

Drone-Based Identification of Containers and Semi-Trailers in Inland Ports:
Jana Teegen, André Peter Kelm, Ole Grasse, Maris Hillemann, Emre Gülsoylu, Simone Frintrop

Addressing Challenges in Creating Traffic Profiles for Transshipment Hubs in Seaports:
Shubhangi Gupta, Marvin Kastner, João Vieira, Carlos Jahn

Tuesday, August 27, 10:00-11:30 h,
Session: Smart Ports

Data Platforms in the Maritime Domain: Challenges and Opportunities

Anisa Rizvanolli, Olaf Rendel[a]

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Abstract. The maritime world is characterized by the complex cooperation of multiple actors along the supply chain. With the rise of digitization, the exchange of information between these actors has shifted from manual to a more automatic process. However, digital communication in this industry often remains at a peer-to-peer level and lacks interoperability or experiences media breaks. Various existing digital solutions, such as data platforms or port community systems, have evolved over time, but fall short in terms of standardization or broad adoption.

This article aims to shed light on the current challenges of such solutions, which have not been extensively addressed by the research community. It also presents a case study of a data platform implemented in the maritime domain, based on open standards like OpenID Connect for authentication and OpenAPI for interface specification. The study provides an overview and discussion of the available technologies and standards and compares recent developments, for example the industry standards from the DCSA, efforts of TIC4.0 Association or the platform specification MCP consortium. Additionally, we assess the governance structures that guide the use of these standards, identify their shortcomings and explore the commercial viability and challenges associated with implementing these open standards in a real-world environment. By analyzing the solutions, the article aims to provide insights into the effectiveness of open standards, interoperability, and governance structures, while also highlighting potential areas for improvement.

Tuesday, August 27, 10:00-11:30 h,
Session: Smart Ports

Keywords: Data Platforms, IT Systems, Seamless Information Sharing, Supply Chain Information Sharing, Maritime Data and Information Exchange, Open Standards

Tuesday, August 27, 10:00-11:30 h,
Session: Smart Ports

Drone-Based Identification of Containers and Semi-Trailers in Inland Ports

Jana Teegen[1], André Peter Kelm[1b], Ole Grasse[2c], Maris Hillemann[1d], Emre Gülsoylu[1], Simone Frintrop[1]

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Abstract. This paper introduces a novel application utilizing drones and deep learning to identify containers and semi-trailers, enhancing inland port operations. With this drone-based image and text recognition system, the basic condition of the yard/storage area can be determined at any time without using (human) labor, eliminating the need for manual inspections. To our knowledge, this is the first instance of identifying containers and semi-trailers in a deep learning application through drone imagery. Automating identification through drone flights is one of the main goals of our InteGreatDrones (IGD) project. This paper lays the foundation and provides a first building block by addressing the challenges posed by the real-world data and the different drone perspectives, including the various altitudes, scenes, and viewpoints captured in this project, with the goal of cargo identification. We use a two-step recognition process, first localizing the text ID and then reading/identifying it. We take established methods such as EAST for scene text detection and TrOCR for optical character recognition and fine-tune them to enable accurate identification from drone imagery. Despite the challenging real-world images, we achieve an F1 of 0.5 for text detection and a CER of 0.16%.

Keywords: UAV-Based Monitoring, Automated ID Recognition, Port Logistics, Loading Unit Identification, Intermodal Handling

Tuesday, August 27, 10:00-11:30 h,
Session: Smart Ports

Addressing Challenges in Creating Traffic Profiles for Transshipment Hubs in Seaports

Shubhangi Gupta[1a], Marvin Kastner[1], João Vieira[2], Carlos Jahn[3]

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[2]Federal University of Rio de Janeiro, Rio de Janeiro, Brazil
[3]Hamburg University of Technology, Hamburg, Germany

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Abstract. Globalization has significantly increased containerized traffic, driven by the rising demand for swift cargo movements at low cost. When creating cost- and time-efficient maritime transport networks, transshipment hubs are of high importance. There, containers are moved from one vessel to another. This enables carriers to design hub-and-spoke networks (where feeder vessels serve the spokes and deep sea vessels interconnect the hubs) as well as connecting deep-sea services by interlining. Hubs are often located along major shipping routes and are concentrated near canals and straits. The successful operation of transshipment hubs relies on various socio-economic factors, trade policies, and robust infrastructure. When making strategic decisions, simulation is often used to estimate the impact of each viable option on terminal performance. Such simulation studies heavily depend on suitable synthetic traffic profiles that reflect the workload and yard occupancy of transshipment hubs over a longer time horizon. Past work has shown that for transshipment hubs, the expected average yard occupancy is approximated over the course of several weeks, which increases the runtime of simulation studies. The approach presented in this paper addresses this issue by modifying the code of library ConFlowGen and applying it on three use cases. The results show that the traffic profiles generated with the modified code are more suitable for simulating operations of transshipment hubs. Several traffic profile characteristics are discussed that are difficult to satisfy at the same time.

Tuesday, August 27, 10:00-11:30 h,
Session: Smart Ports

Keywords: Container Terminal, Port Planning, Synthetic Data Generation, Maritime Transport, ConFlowGen

Intermodal Transport

Tuesday, 27.08.2024, 10:00-11:30, Room 122

Chair:Christian Bierwirth

Competitive Service Network Design and Pricing for Intermodal Transport:
Adrien Nicolet, Bilge Atasoy

Route Planning with Heterogeneous Environmental Preferences of Shippers:
Justin Wittig, Christian Bierwirth

AI-Based Delay Estimation for Freight Trains:
Chhandosee Bhattacharya, Anisa Rizvanolli, Ole John

Tuesday, August 27, 10:00-11:30 h,
Session: Intermodal Transport

Competitive Service Network Design and Pricing for Intermodal Transport

Adrien Nicolet[a], Bilge Atasoy

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Abstract. The design of transport services as well as their prices are the most important tactical decisions faced by an intermodal transport operator. The recent Service Network Design and Pricing models tend to include more detailed behavioral elements regarding the transport demand. However, they do not consider the reaction of competing transport operators to the services and prices proposed by the decision maker. Moreover, very few models consider decision making with incomplete information. In this work, we address these limitations by including competition and assuming that operators only have information about their own market shares and the ones of their competitors. The model is then applied to a real segment of an intermodal corridor to verify its functioning. The results highlight the impact of the assumptions on the model's solution. Moreover, the influence of the operators' fleet on the solution is explored, as well as the impact of full and limited information levels. Finally, the results reveal that the first operator to make a decision has a significant advantage.

Keywords: Intermodal Transport, Network Design, Pricing, Competition

Tuesday, August 27, 10:00-11:30 h,
Session: Intermodal Transport

Route Planning with Heterogeneous Environmental Preferences of Shippers

Justin Wittig[a], Christian Bierwirth

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

Keywords: Heterogeneous Fleet Vehicle Routing Problem, Eco-Preferences, Greenhouse Gas Emissions

Tuesday, August 27, 10:00-11:30 h,
Session: Intermodal Transport

AI-Based Delay Estimation for Freight Trains

Chhandosee Bhattacharya[a], Anisa Rizvanolli[b], Ole John[c]

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Abstract. Train transportation plays a crucial role in supporting the operations of the maritime industry. They provide an efficient, cost-effective and environmenttally friendly transportation between seaports and inland distribution centres, quickly shipping large volumes of cargo over long distances. With scheduled services and dedicated rail networks, rail transport provides a higher level of reliability and predictability.

Managing train arrivals is an important challenge for inland terminals. Terminals typically operate within strict time constraints leaving little room for delays or disruptions. Delay in freight trains can disrupt terminal processes and lead to inefficient resource planning and customer dissatisfaction. Therefore, it is imperative to have early information about changes in expected arrival times (ETA) of cargo trains such that logistic processes and resource allocation can be coordinated accordingly.

In recent years, multiple studies were conducted to forecast train delays and determine factors affecting it. They provided a comprehensive knowledge about the performance of various algorithms ranging from regression to gradient boost and artificial neural networks. However, most studies were focused on passenger trains and research related to freight trains was very limited. This paper focuses on delay estimation for freight trains. Additionally, it tackles the issue of constantly changing intermediate stations for running trains and for journeys on the same route.

Tuesday, August 27, 10:00-11:30 h,
Session: Intermodal Transport

The aim of this study was to predict delay of freight trains arriving at a terminal in Nürnberg considering various factors like historical delay information, calendar data, geographical and meteorological parameters. The task was designed as a sequence prediction problem and a multi-step multi-variate LSTM model was used to achieve the goal. The chosen model offered an advantage of capturing spatio-temporal dependencies and handle non-linear relationships in a multi-variate setting.
With this study, it was possible to observe the busiest routes to Nürnberg, the distribution of delays across different states of Germany, patterns of lateness in freight trains throughout the day/week and achieve a realistic estimation compared to existing baseline methods. It has a great potential to boost terminal efficiency because an early information of train arrivals can help in optimally allocating equipment, staff and storage capacity. Moreover, sharing the information with inland distributers would be beneficial to find alternate solutions in advance and enhance customer satisfaction.

Keywords: Train Delay Prediction, Freight Transport, Data-Driven Models, LSTM

Container Stacking & Storage

Tuesday, 27.08.2024, 10:00-11:30, Room 123

Chair: René de Koster

Q-Learning for Outbound Container Stacking at Container Terminals:
Aaron Lim, Seokchan Lee, Jeongyoon Hong, Younghoo Noh, Sung Won Cho, Wonhee Lee

Enhancing Port Efficiency: A Simulation-Based Study of Container Reshuffling in the Container Yard:
Mengya Liu, Xin Chu, Zexin Lin, Haobin Li

Determining the Throughput capacity of Mixed-Load Multi-Deep Storage and Retrieval Systems:
René De Koster, Timo Lehmann

Tuesday, August 27, 10:00-11:30 h,
Session: Container Stacking and Storage

Q-Learning for Outbound Container Stacking at Container Terminals

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Abstract. The efficient stacking of outbound containers presents a significant challenge within container terminal operations. It's crucial to minimize the anticipated need for rehandling, as this directly impacts yard productivity and overall terminal efficiency. To address this challenge, we introduce a novel approach based on reinforcement learning. Our method employs Q-learning, incorporating Monte Carlo techniques to identify optimal storage locations by maximizing reward values. Furthermore, we've developed effective strategies for determining storage placements through extensive training iterations. Through numerical experimentation using realworld container terminal data, we've compared our model with existing algorithms. Numerical results highlight the robustness of our approach in navigating uncertain operational environments, its ability to support real-time decision making, and its effectiveness in minimizing rehandling requirements.

Keywords: Container Terminal, Q-Learning, Yard Management, Container Stacking Problem

Tuesday, August 27, 10:00-11:30 h,
Session: Container Stacking and Storage

Enhancing Port Efficiency: A Simulation-Based Study of Container Reshuffling in the Container Yard

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1. Introduction

Singapore stands as the world's busiest container transhipment hub by tonnage, welcoming over 130,000 vessel visits annually and ranking as the foremost bunkering port globally. Strategically positioned at the centre of trade routes, Singapore links to 600 ports across 120 countries, providing unrivalled connectivity for businesses and shipping lines. These ports act as vital bridges connecting the East and West, stimulating economic development and powering international supply networks. Efficient operations within port facilities are vital for keeping trade flowing smoothly and minimising delays. Additionally, maintaining optimal efficiency would significantly cut down operation costs and enhance the overall port productivity. In the context of Singapore's ports, efficiency is not just a desirable attribute but a fundamental necessity to sustain its position as a premier maritime centre. One of the primary challenges faced in maintaining a high level of operational efficiency is reshuffling. While stacking containers on top of each other to maximise yard space utilisation, accessing a target container in the lower tier, obstructed by others, sometimes requires additional effort. This additional movement of repositioning blocking containers, referred to as reshuffling, is unproductive but often unavoidable. Effectively managing it is crucial to ensure an optimal use of the storage space and facilitate an efficient retrieval. In this study, we delve into the reshuffling problem within port operations. By leveraging simulation modelling techniques, we aim to delineate the intricacies of this dynamic problem and propose strategies to enhance operational efficiency and robustness. Through simulations and scenario analysis, we aim to derive insights that can help stakeholders make informed decisions and, therefore, contribute to the sustainable development of the maritime infrastructure.

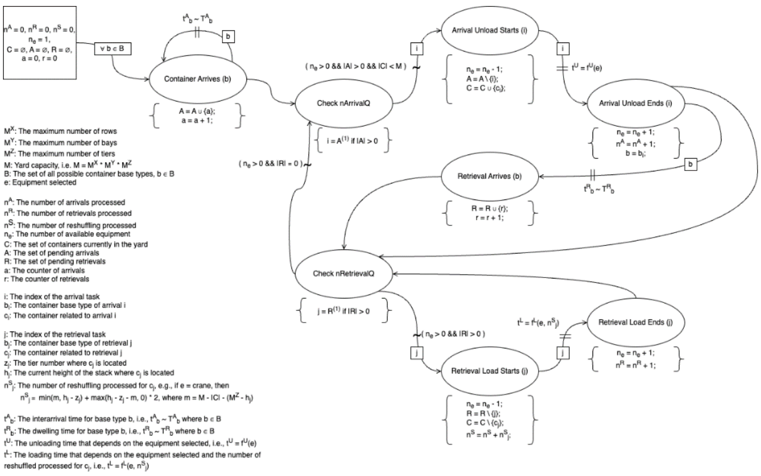
2. Methodology

The reshuffling problem within container terminals is inherently stochastic, dynamic, and complex. Container terminals operate in a dynamic environment marked by fluctuating cargo volumes, diverse vessel schedules, and ever-changing demand patterns. These factors necessitate constant container reorganization to ensure the smooth handling of incoming and outgoing shipments. The container reshuffling problem is closely linked to a range of port planning decisions, such as facility layout design, material handling equipment selection, and stacking policy evaluation, while also being affected by constraints imposed by their availability. These selection problems could further complicate the situation, often leading to the reshuffling problem being hard to investigate and searching for the optima. For example, when assessing the utilisation of overhead cranes versus forklifts in yard operations, both options offer distinct advantages and drawbacks. Forklifts access containers from the side, facilitating short processing times, whereas overhead cranes access containers from the top, typically requiring longer processing times compared to forklifts. However, the efficient use of forklifts demands significant space for manoeuvring, potentially reducing the area available for container storage. To compensate for this downside and enhance space utilisation, stacking heights may need to increase. Yet, this can exacerbate the need for reshuffling, ultimately. hindering operational efficiency. Balancing these considerations is crucial in devising a yard layout and operation strategy that optimises space utilisation without compromising productivity. To tackle the complexity of the problem, we have constructed a sophisticated simulation model using the Object-Oriented Discrete Event Simulation (O^2DES) framework with an implementation of C#. It allows us to thoroughly investigate various decision problems and devise effective strategies by adeptly unravelling the intricacies of port operations. O^2DES is a simulation framework introduced by Li et al. (2016); it provides a structured environment for efficiently developing discrete event simulation models. This framework structurally organises a system into three core components: statics, dynamics and events (Li et al., 2017). The statics component delineates the characteristics and properties of the system being simulated, while the dynamics component captures the interaction between events and content updates of state variables. The events are the transitions of status variables from one state to another. O^2DES offers a diverse array of functionalities that support seamless integration with optimisation techniques. Different from other commercial and open-source simulation packages relying on activity-based formalism, O^2DES adopts a hybrid approach incorporating both event-based and state-based formalism with an object-orientedprogramming language. With its event-based core, O^2DES excels in precisely modelling system structures and behaviours, ensuring optimal flexibility in representing the complexities of the real world. On the other hand, state-based formalism facilitates modularisation and hierarchical modelling. Moreover, the object-oriented paradigm abstracts model definitions, facilitating seamless interaction with analytical capabilities and allowing for a flexible adjustment to different levels of fidelity as necessary. A local company has approached us for assistance in addressing reshuffling challenges. They have sought our expertise in analysing how stacking height alongside different types of material handling equipment influences yard operation efficiency. To address this specific case, we customised the simulation model and executed a tailored experiment, delving into the relationship between stacking height and two critical yard operation metrics. Our analysis of these metrics aims to provide actionable insights for optimising operations and enhancing overall efficiency within the port environment.

Storage Efficiency: It quantifies the number of containers that can be accommodated within a given land area, and it is inherently tied to stacking height.

Handling Efficiency: When evaluating handling efficiency, it is crucial to encompass not only productive moves (termed "In" and "Out" moves) but also unproductive moves, particularly those associated with reshuffling. Within our simulation, we use the adjusted processing rate, defined as the inverse of the processing time per effective move, to reflect the handling efficiency. The adjusted processing rate not only captures the effect of the reshuffling but also considers the stability of material handling equipment.

In our simulation setup, containers are categorised into distinct base types and grouped into batches based on their arrival days. The time intervals between consecutive arrivals of specific base types follow the probabilistic pattern, which introduces stochastic elements into our modelling and reflects variability observed in practical scenarios. To mirror real-world operations, we adhere to the "Homogeneity Rule" when unloading containers. This rule serves as the guiding principle for allocating arriving containers to specific stacks, ensuring systematic and efficient container placement. After a container is unloaded, a retrieval event specific to its base type is scheduled based on dwelling time distributions, signifying the moment when containers are being called for departure from the yard. It is to reflect the dynamic flow of containers as they enter and exit the yard. It is worth noting that during the execution of retrieval events, we implement the "First Come, First Serve" principle. This means that the retrieved container must come from the earliest batch of the requested base type. It ensures a fair and prompt retrieval and prevents older stock from remaining in the yard for extended periods. If other containers block the access to the target retrieval container,



reshuffling will take place. Figure 1 illustrates the event graph depicting the container operation described above.

Fig.1: Event Graph for Typical Container Operations

We investigate two types of material handling equipment: overhead cranes and forklifts, each offering distinct operational characteristics. Moreover, we explore two scenarios: one with minimal variation between containers comprising a small number of base types and another with substantial variation including a significant quantity of base types. This allows us to assess the adaptability and efficiency of yard operations across a range of equipment choices and operational complexities, providing comprehensive insights for tailored decision-making and optimising container yard management strategies.

3. Preliminary Result

The stacking height in Figure 2 refers to the average stacking height observed when the simulation reaches steady-state conditions. This value is derived according to Little's Law, by multiplying the arrival rate and dwelling time and then dividing the result by the number of available ground slots. It is evident that, by definition, the storage efficiency is proportional to the stacking height for all the circumstances, as depicted by the grey curve in Figure 2. In line with industry practices, we've established an operational stacking height limit of six. This limit indicates that, during regular operations, a maximum of six containers can be stacked on a ground slot. The red and red dotted curves illustrate how handling efficiency changes with the stacking height when overhead cranes are employed as the material handling equipment, representing scenarios with low and high container variation, respectively. In contrast, the blue and blue dotted curves depict the same changes but for the forklift cases. Figure 2 clearly demonstrates the decline in handling efficiency with increasing stacking height, primarily due to an increase in the percentage of unproductive moves caused by reshuffling. When the stacking height is relatively low, only a few reshuffling moves occur, making forklifts a preferable choice due to their shorter processing time per container. Nevertheless, this advantage diminishes as stacking height increases because the demand for reshuffling operations with forklifts escalates at a faster rate compared to overhead cranes due to the difference in their operational characteristics.

Furthermore, when comparing the blue dotted and blue curves, it becomes evident that handling efficiency experiences a steeper decline with stacking height in scenarios characterised by a high variation in container types compared to scenarios with low variation when forklifts are used. The same observation holds for the crane case, as shown by the red dotted and red curves. However, this decline is less significant, suggesting that handling efficiency in the crane case is less sensitive to the impact of variations in container types and stacking height compared to the forklift case. In conclusion, in scenarios with a limited variety of base types, forklifts exhibit a greater handling efficiency at lower stacking heights. Conversely, when dealing with a diverse range of base types, overhead cranes demonstrate superior performance, particularly at higher stacking heights.

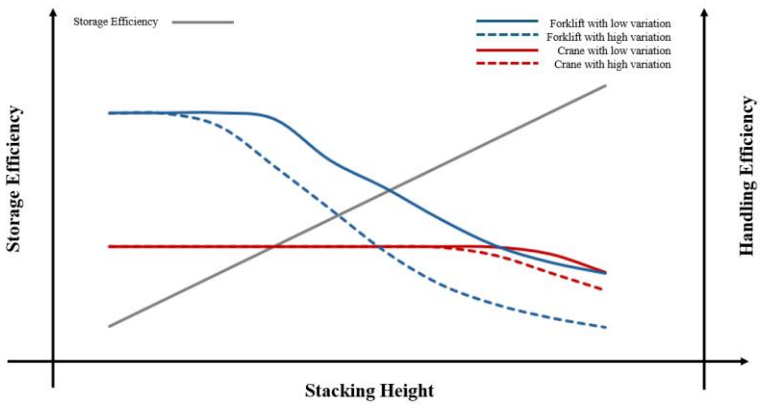


Fig.2: Storage and Handling Efficiency versus Stacking Height

4. Roadmap

Our simulation model is designed with adaptability at its core. It is not limited to container yards alone but can also be readily applied to container depots and other port facilities. This flexibility enables ist effective utilisation across a wide range of configurations and scenarios. Having laid the groundwork for our model, in our initial phase, we have established the model's utility by focusing on the container reshuffling problem and investigating the factors influencing operational efficiency. Moving forward, our research trajectory shifts towards identifying the most effective configuration or resource allocation strategy. This involves a comprehensive exploration of equipment allocation, yard block configuration, and other related design or decision problems. To maximise the simulation efficiency in identifying the optimal decision, we will adopt Optimal Computing Budget Allocation (OCBA) techniques (Chen, 1995;

Chen et al., 2009; Chen & Lee, 2010) to guide us in allocating the computing budget for each candidate. As our study progresses toward its completion by the end of 2024, our simulation model emerges as a useful tool for addressing real-world efficiency, capacity, and planning challenges within port logistics.

Keywords: Container Reshuffling, Port Logistics, Maritime Studies, Discrete Event Simulation, Object-Oriented Discrete Event Simulation

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Tuesday, August 27, 10:00-11:30 h,
Session: Container Stacking and Storage

Determining the Throughput capacity of Mixed-Load Multi-Deep Storage and Retrieval Systems

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Abstract. Multi-deep storage systems are space-efficient storage solutions for e-commerce and spare part logistics. Popular types are robotic compact storage and retrieval (RCS/R) and multi-deep automated storage and retrieval (AS/R) systems. In such systems, multiple loads can be stored behind or above each other in a single lane, which leads to high space utilization. However, blocking loads must be reshuffled if they block a requested load. This increases the command cycle time. We present models to estimate the throughput capacity of these systems. We build these models using four different storage assignment strategies, three different load reshuffling strategies and two retrieval load selection strategies, incorporating the access frequency of products and allowing multiple stored loads per product. The throughput capacity is determined using closed queuing networks (CQN), where the service times are based on the channel steady-state distributions, which are derived using Markov-chain models. We find that the class-based storage assignment strategy, where different classes share the same lanes (CBS-3-RBP), yields the highest throughput capacity. Based on the throughput model, we optimize the rack layout yielding maximum throughput capacity and provide managerial insights on storage assignment, reshuffle and retrieval load selection.

1. Introduction

In recent decades, the introduction of various automated compact warehouse storage systems has transformed the logistics landscape. These storage systems use multi-deep storage lanes to efficiently store products. Examples of these systems are multi-deep automated storage and retrieval (AS/R), robotic compact storage and retrieval (RCS/R), and multi-deep autonomous vehicle storage and retrieval (AVS/R) systems. A comprehensive overview of such systems is provided by Azadeh et al. [2]. Multi-deep (or deep-lane) storage systems are characterized by a high space utilization and, for some systems, high throughput capacity. Consequently, they find application in many distribution centers and spare-part warehouses. In these systems, stored loads (totes, bins, pallets, containers) are arranged in multi-deep storage lanes (or channels), either behind one another in a storage lane (as in AS/R and AVS/R systems), or they are stacked vertically (as in RCS/R systems or sea-container stacks). Load-handling devices (cranes, robots, shuttles) cannot directly access each load. When a blocked load needs retrieval, the system must reshuffle the blocking storage loads. In systems like AutoStore, the reshuffled loads must also be brought back to the original location, to ensure that loads of frequently requested products float to the top of the system ([1],[5]). This all adds to the command cycle time and it may decrease system throughput capacity, a critical performance indicator at the design stage.

The operator's challenge lies in efficiently storing and retrieving loads while minimizing the number of reshuffles. When a new system must be designed, it is important to be able to estimate up-front the impact of the design and operating strategies on the throughput capacity. Operating strategies include the storage assignment (i.e., the channel use policy, such as shared storage of loads of different products in a channel or dedicated storage of only loads of the same product), reshuffle, and retrieval load selection strategies (when multiple loads of a requested product are stored). When information on access frequency of different products and the number of loads per product to be stored in the system are known, sophisticated storage assignment policies, like class-based storage or smart retrieval selection strategies can be used. We address the following research question: How do the different storage assignment, reshuffle, and retrieval load selection strategies perform and which strategy combination maximizes the long-run throughput capacity? We also investigate the strategy used by the market leader AutoStore for RCS/R systems (the AutoStore strategy [1] is explained by Meller [5]) and compare it to other combined strategies and investigate how information on the product access frequency and the stored number of loads per product can be used to improve the throughput capacity. We then use this knowledge to find the optimal rack layout of a multideep RCS/R or AS/R system of a given storage capacity that maximizes the throughput capacity.

2 Modeling Approach

We focus on RCS/R systems (and later extend our models to multi-deep AS/R systems), like AutoStore and distinguish 4 different storage strategies for storing loads, 3 strategies to position blocking loads that need to be reshuffled, and 2 load selection strategies (in case more than one load of product is stored). These are summarized in Figure 1. To estimate the throughput capacity of a given RCS/R system, we use a closed queuing network (CQN) with two server nodes (see Figure 2). In a CQN, retrieval jobs are always available, and robots do not have to wait for new command cycles, which makes them fit to estimate the throughput capacity of new systems to be designed.

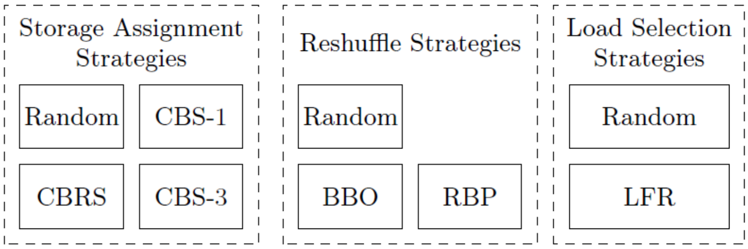

Fig. 1: Operating strategies for storage, reshuffling, and load selection.

BBO = Bring Back to Original Channel; CBRS = Class-Based Random Storage;CBS-1 = Class-Based Storage with one Class per Channel; CBS-3 = Class-Based Storage with 3 Classes per Channel; LFR = Load with Fewest Reshuffles; RBP = Relocate Best Position.

The time needed for reshuffles, retrieval, and storage of a dual-command cycle is assumed to be an exponentially distributed delay process (an infinite server, denoted by IS), with mean μ_{rack}^{-1}. This is justified, as there are many different shortest paths between the retrieval channel and the pick station, so congestion is minimal. The service time of the pick station μ_{pick}^{-1} is assumed to be exponentially distributed and the queuing discipline is FCFS. Robots may have to queue at the pick station while the operator is still handling a previous load. There are *K* robots circulating in the network dedicated per pick station.

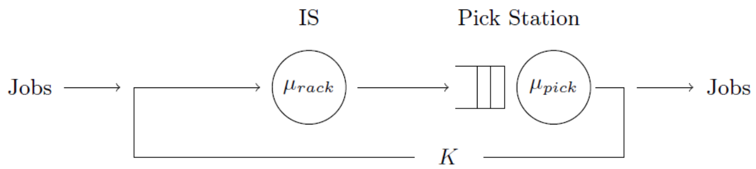

Fig. 2: Closed queuing network with K robots and two server nodes.

Using Little's law, the throughput capacity of the network TP, in retrieved totes per hour, equals $TP = \frac{3600 \cdot K \cdot PS}{\mu_{rack}^{-1} + \mu_{pick}^{-1} + t_{wait}}$, where t_{wait} is the mean waiting time of retrieved totes at a pick station, and PS is the number of pick stations, grouped around the center of the long sides of the system. The network can be analyzed using Mean Value Analysis. The difficulty lies in deriving the mean time of a dual-command cycle μ_{rack}^{-1}..This time depends on the combinations of storage, reshuffle and load selection strategies. For each of these combinations, we need to calculate 1) the probability that a load of a certain class will be selected from a specific channel type, 2) the expected number of reshuffles required, and 3) for every type of movement (reshuffling, retrieval, storage) how much expected time it will take. This then determines the mean total movement time. Both the movement times and the number of reshuffles depend on the steady-state distribution of the channel types $c_{h,k}$, where $h = 1, ...,H$ is the number of loads in the channel, with H as the system height, and $k = 1, ..., J^h$ as the channel type index (with J the number of storage classes, typically 3 in total). The steady-state probabilities $\pi(c_{h,k})$ can be derived from the Markov chain and the conditional storage $P(S_i|c_{h,k})$ and retrieval probabilities $P(R_i|c_{h,k})$, for a load of class $i = 1, ..., J$.

3. Results

The assessment of the seven distinct operational strategies of Table 1 yields valuable insights for storage planners. We first compare different combinations of the strategies against the prevailing AutoStore strategy and a random baseline strategy (for storage, reshuffling and selection). The strategy CBS-3-RBP, which is a combination of 3-class-based storage with products of multiple classes in a single channel (different from e.g. Zou et al. [8], Eder [4] and Cardin et al. [3], who use class-based storage per channel), locating reshuffled loads to their best position (i.e. not back to the original position which is different from Yue and Smith [7] and Tutam et al. [6]), and selecting the load of a product that leads to the fewest reshuffles (LFR), appears to outperform the other combinations for throughput capacity. The AutoStore strategy performs comparably to a random selection. Depending on the channel height H, and the number of loads per product, the CBS-3-RBP strategy generates up to 100% higher throughput capacity than AutoStore, with the same number of robots. We also find upper and lower bounds for the optimal length-to-width ratio in RCS/R systems, and the configuration that minimizes operational cost. Our findings also demonstrate that integrating more available information on the number of loads per product and the access frequency of products across different classes, significantly enhances the throughput efficiency of a given storage system.

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

Keywords: Multi-Deep Storage, Throughput Capacity, RCS/R System, Travel Time Modeling

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Smart Terminals

Tuesday, 27.08.2024, 12:00-13:30, Room 121

Chair: Leonard Heilig

TwinSim: Development of a Digital Twin for Container Terminals:
Leonard Heilig, Paul Kokot

Using Activity-Based Formalism to Analyse a Container Terminal Model in FlexTerm:
Changying Shao, Haobin Li, Tianhao Chen, Zexin Lin

Performance Estimation of Twin Cranes in Container Terminals: *Ningning Song, Kap Hwan Kim, Xuehao Feng*

Tuesday, August 27, 12:00-13:30 h,
Session: Smart Terminals

TwinSim: Development of a Digital Twin for Container Terminals

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Abstract. Digital twins allow to precisely reflect the state of container handling equipment and operations at container terminals by integrating various technologies. This builds the basis for advanced data-driven decision support. In the project TwinSim, a digital twin is developed for the EUROGATE Container Terminal Hamburg (CTH), Germany, to provide a live visualization of terminal activities and enable data-driven decision making regarding maintenance activities and operational planning and optimization. In this presentation, we give an overview on key aspects of implementing an IoT- and cloud-based digital twin for a container terminal and present results from the project.

Keywords: Container Terminal, Digital Twin, Cloud Technologies, Data-Driven Decision Support

Tuesday, August 27, 12:00-13:30 h,
Session: Smart Terminals

Using Activity-Based Formalism to Analyse a Container Terminal Model in FlexTerm

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1. Introduction

A digital twin is a computerised replica of a real-world system, where each element is represented digitally. It is a virtual representation of an object or system that spans its lifecycle, is updated from real-time data, and uses simulation, machine learning and reasoning to help in decision-making processes. While numerous commercial software solutions facilitate the construction of digital twin models, FlexTerm stands out as a comprehensive and widely adopted tool, particularly in simulating container terminal operations. Among many types of simulations, the discrete-event simulation (DES) model is the best way to specify man-designed systems and analyse any decision involved in such systems. Object-Oriented DES (O²DES) represents an open-source simulation framework introduced by Li et al.(2016), which is a hybrid simulation modelling formalism designed to enhance digital twins (Schleich et al., 2017).

This abstract introduces a novel approach for scrutinising the fidelity of a comprehensive FlexTerm container terminal model using Entity Flow Diagrams (EFD) within the O²DES framework. Unlike traditional "activity-based" methods, our hybrid modelling formalism employs "state-based" modules to encapsulate one or more activities while utilising an "Event Graph" to define discrete event logic and activity interactions. This innovative approach allows for the concise representation of dynamic terminal operations and facilitates tracking entity flow directions across module boundaries. Through this examination, we demonstrate O²DES's prowess in scrutinising mainstream commercial software with enhanced accuracy and foresight.

2. Methodology

As illustrated in Figure 1, within the comprehensive FlexTerm terminal, the container operations are meticulously organised into four distinct sectors: berth, rail, gate, and yard.

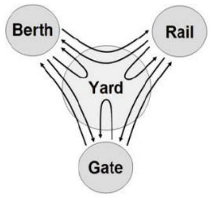

Fig.1: FlexTerm Modeling Operation Sectors (extracted from *FlexTerm Help*)

At the berth, a diverse array of ships adheres to schedules, where cranes and trucks load and unload containers onto and off the vessels, ensuring operations within precise timeframes. Similarly, the rail sector operates on predetermined schedules, accommodating various trains with the aid of cranes, trucks, and specialised yard blocks, facilitating efficient servicing of incoming and outgoing trains. The gate sector serves as the primary entry point for trucks from the civilian road network, enabling smooth ingress and egress, thereby facilitating the flow of goods in and out of the terminal smoothly. Lastly, the yard sector serves as a strategic buffer for container storage, allowing containers to be housed for a specified dwell time, optimising terminal space utilisation and facilitating organised container movement within the facility. Together, these four sectors form the backbone of the FlexTerm terminal, ensuring efficient and synchronised operations essential for meeting the dynamic demands of modern supply chains.

The Entity Flow Diagram (EFD) is a modelling technique based on the O²DES framework that is used to visually represent the flow of entities through a system over time. We first identify each moving component in the system, which we refer to as a "flowing entity". For each flowing entity, we break down the total time it spends in the system into stages based on resource utilization or their impact on other parts of the system. Each stage of a flowing entity is termed an "activity". In the modeling process, we can treat each activity as a logical module. Alternatively, we can group activities associated with a specific type of resource into a single logical module, or resource entity module. Therefore, EFD is valuable for understanding system behaviour, identifying bottlenecks, and optimising processes within a digital twin or simulation model.

As depicted in Figure 2, the interaction within the Entity Flow Diagram (EFD) encompasses various activities, involving six types of interactions between each pair of activities. These interactions include Flow, StartToInflow, StartToStart, StartToFinish, FinishToStart, and FinishToFinish.

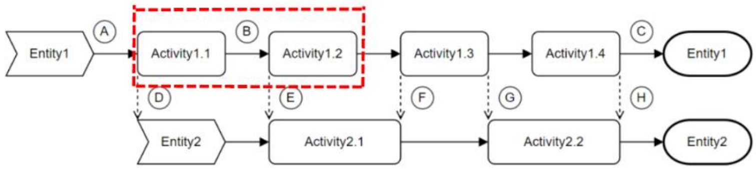

Fig.2: An Example of Interactions between Different Activities in EFD

The significance of different arrows is elucidated as follows:

A: Represents the first activity for the entity.
B: General interaction between two consecutive activities.
C: Denotes the final activity for the entity.
D: Indicates the transition from Start to Inflow.
E: Represents the transition from Start to Start.
F: Depicts the transition from Start to Finish.
G: Signifies the transition from Finish to Start.
H: Represents the transition from Finish to Finish.

Unlike traditional "activity-based" methods, Entity Flow Diagrams (EFD) enable modularisation. An EFD can be divided into multiple modules, such as the segment highlighted in the red box in Figure 2. The interaction type Flow occurs between two consecutive activities of the same entity (as shown in the red box of Figure 2. and Figure 3.). When an entity completes its trip in Activty 1.1, the event OnReadyToDepart of Activity 1.1 is triggered along with the associated event, the event RequestToArrive of Activity 1.2. Subsequently, when the entity enters Activity 1.2, Activity 1.1 is notified that the entity can depart, triggering the outgoing signal OnArrived along with its associated event, the event Depart of Activity 1.1.

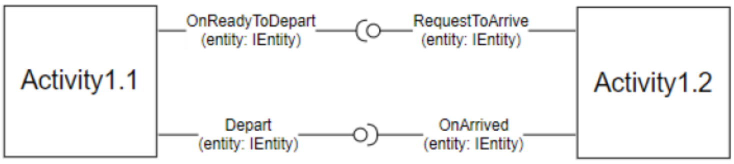

Fig.3: General Interaction between Two Consecutive Activities

Furthermore, individual activities can extend to modular event graphs. Ultimately, EFD facilitates standardised module division and interface definition, ensuring compatibility among conforming modules (Li et al., 2020, 2022). In the context of FlexTerm or similar systems, EFD could depict how containers move through the various sectors of the terminal, such as from the berth to the yard or from incoming trains to outgoing trucks.

3. FlexTerm Model Analysis

3.1 Flowing Entities

To construct a digital twin simulation model, the initial step involves the objects to be processed and the operational processes, designated as entities and activity flows, respectively. Flowing entities can be categorized into two types: load entities and resource entities, each playing distinct roles in the system. Subsequently, customized activity flows are developed for each entity type. Additionally, various strategies are devised to facilitate decision-making processes. All of these components collectively contribute to the construction of a comprehensive digital twin simulation model. Within the FlexTerm simulation model, load entities, such as ships, trains, external trucks, and containers, undergo a life cycle within the model, ultimately exiting upon completion. On the other hand, resource entities, including quay cranes, internal trucks, yard cranes, and rail RMGs (Rail Mounted Gantries), persist permanently once created, contributing to the operational infrastructure of the terminal.

3.2 Subsystems

According to the analysis of hybrid simulation formalism, a complete FlexTerm digital twin model consists of five subsystems: berth area, yard area, gate portion, track area, and transportation system. Each subsystem within the terminal serves unique functions and accommodates a variety of activities.

In the berth area, the geometry of the berth is defined by two docking points where ships can moor and cranes operate for container handling. Upon model running, internal trucks can facilitate container discharge and loading operations at the berth area. The yard area comprises multiple yard blocks amalgamated into a container storage zone, acting as the central hub for container operations. Every container must traverse the yard before reaching its destination. Notably, the yard area does not encompass road infrastructure. The gate portion encompasses gate roads, queues, processing areas, and sinks, delineating the flow of trucks entering and exiting the terminal. Activities in the gate section include external trucks transporting containers between the gate portion and the yard area. In the track area, multiple rail blocks form a dedicated space for trains to arrive and depart, facilitating the transportation of containers through the terminal. Lastly, the transportation system encompasses travelling paths and internal trucks traversing these paths. However, if internal trucks are engaged in activities elsewhere, such as loading or unloading containers, they are not considered part of the transportation system. Paths serve as connectors between different subsystems within the terminal, facilitating the seamless flow of goods throughout the facility.

3.3 EFD

As shown in Figure 4., the EFD visually depicts the dynamic operations of load entities: Train, Ship and Container. The partial EFD in the red box for describes the process of discharging containers from ships, and the three resource entities are essential for container handling within the terminal. The arrow with a number means the interactions between container activities and resource entity activities.

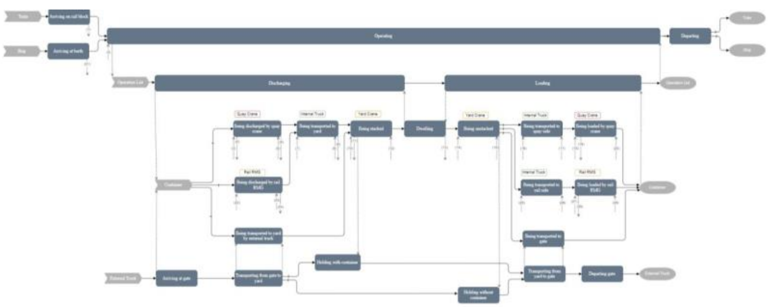

Fig. 4: EFD for Load Entities in FlexTerm Model

Figure 5 shows EFDs for three key resource entities: Quay Crane, Internal Truck and Yard Crane. Due to space limitation, we only analyse discharging containers from ships in details which is one the most important activities in the terminal.

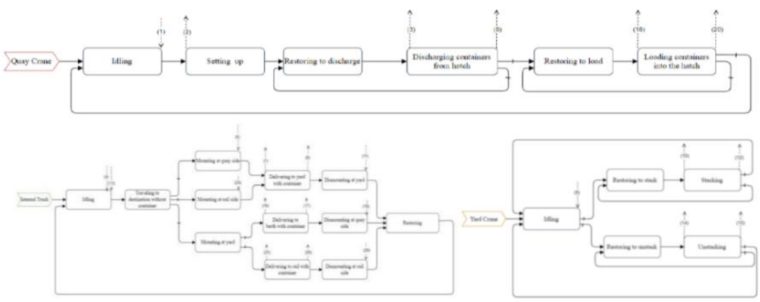

Fig.5: EFD for Resource Entities in the FlexTerm Model

The start of the activity "Discharging containers from hatch" for the quay crane triggers the start of "Being discharged by quay crane" for the container (arrow 3). Upon initiation of the latter, the end of "Idling" for the internal truck is triggered (arrow 4). The internal truck then proceeds to the quay side for mounting. After the container is discharged by the quay crane, the end of "Discharging containers from hatch"for the quay crane triggers the end of "Being discharged by quay crane"of the container (arrow 5), which ends "Mounting at quay side" for the internal truck (arrow 6). Consequently, the internal truck transports the container to the yard, signifying the beginning of "Delivering to yard with container", which in turn triggers the start of "Being transported to yard" (arrow 7). Once the transportation is completed, the end of "Delivering to yard with container" triggers the end of "Being transported to yard" (arrow 8), thereby ending the "Idling" of the yard crane (arrow 9). After returning to the stack, the yard crane starts stacking. The initiation of "Stacking" for the yard crane triggers the start of "Being stacked" for the container (arrow 10), which can prompt the end of "Dismounting at yard" for the internal truck (arrow 11), enabling the internal truck to resume operations. Finally, the end of "Stacking" of the yard crane triggers the end of "Being stacked" for the container (arrow 12).
In conclusion, tracing the flow direction of each entity can clearly elucidate how the subsystems interact with each other. Through

meticulous analysis, we can provide a more detailed and accurate description of the operations of the FlexTerm model or other digital twin models, thereby analysing its underlying logic and pinpointing areas for improvement and enhancement.

Keywords: Discrete-Event Simulation, Activity-Based Formalism, Container Terminal Model, Entity Flow Diagram, Object-Oriented DES

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Tuesday, August 27, 12:00-13:30 h,
Session: Smart Terminals

Performance Estimation of Twin Cranes in Container Terminals

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Abstract. It is important to estimate the performance of yard cranes in a short time for designing the handling system in container terminals. This study proposes a method to rapidly evaluate the performance of twin cranes which are popularly used in automated container terminals. Statistical analysis is done for estimating the interference time between twin cranes as well as gantry travel time. Different handling procedures of twin cranes for loading, discharging, carry-in, and carry-out operations are considered. In addition, it is discussed how the storage location strategy affects the performance of crane systems, especially, the strategy based on the duration-of-stay of containers for loading operations.

1 Introduction

With the growth of automated container terminals, twin crane interference has been found to impact terminal efficiency and cause yard congestion. Decisions on yard design and crane deployment are crucial to the performance of twin cranes. Specifically, assessing average service time for different container types is necessary for efficient task allocation in the yard.

There are few previous studies about the estimation of the yard crane performance. Kim [1] proposed a methodology estimating the number of container rehandles for a given number of stacks and the given number of tiers in a bay. Lee and Kim [2] derived the mathematical expressions of the yard cycle time for determining the best block size in container yards. They proposed expressions for estimating the cycle time needed for loading, unloading, receiving and delivery operations. Lee and Yu [3] discussed about the probability distribution of container duration of stay (DOS), which will be used for designing a DOS-based storage location strategy in this study. The scheduling performance of a twin crane shows different characteristics under different proportions. Munim and Schramm [4] showed that the ratio of different types of containers at a port is primarily influenced by the region's economic structure, resource distribution, and the port's geographical location.

2 Components of the cycle time of twin cranes for various types of operation

In the yard, the container types can be classified into three categories: import, export, and transshipment containers. Each container type is involved in two distinct operations. Specifically, import containers are associated with the process of discharging and carry-out, while export containers are engaged in carry-in and loading operations. Also, transshipment containers are involved in both the loading and discharging operations. A detailed depiction of the cycle time components corresponding to each operation type can be found in Table 1.

Operation Type	Cycle time components				
Carry-in	Travel time to the end of block	Pickup time	Travel time to the destination slot	Release time	
Carry-out	Travel time to the destination slot	Rehan-dling time	Pickup time	Travel time to the end of block	Release time
Loading	Travel time to the destination slot	Pickup time	Travel time to the end of block	Release time	
Discharg-ing	Travel time to the end of block	Pickup time	Travel time to the destination slot	Release time	

Table 1. Cycle time for various types of operation

In Table 1, the pick-up time and release time are relatively easy to obtain. However, because the travel time needs to consider the interference between cranes, and the re-handling time needs to consider the number of rehandles to pick up the target container, it is necessary to discuss about the travel time and rehandling time in more detail.

3 Analysis of the number of rehandles for carry-out operation

The evaluation of the number of rehandles is import for estimating the rehandling time. Kim [1] proposed a formula for estimating the total expected number of rehandles for carrying out all the import containers from one bay. For the estimation of the rehandling time, the expected number of rehandles needs to be estimated.
Let a variable V be the space utilization at the moment when the carry-out operation happens, and θ be the initial space utilization of the carry-out container bays, and the number of tiers and rows in one bay be n_T , n_R respectively. The expected number of rehandles for a carry-out operation can be derived as follows from Kim (1997):

$$\int_0^\theta \left(\frac{n_T-1}{2}+\frac{n_T+2}{8n_R}\right) V \frac{1}{\theta} dV = \theta\left(\frac{n_T-1}{4}+\frac{n_T+2}{16n_R}\right) \quad (1)$$

4 Analysis of the probability of interference for random location

Suppose that the storage locations of arriving containers are determined randomly. One import container is to be moved from the end of the sea side to the end of the land side and one export container is to be moved in the opposite direction. Wherever the two containers are stored, the trajectories of SC for discharging and LC (land-side crane) for carry-in must be overlapping or the trajectories of SC (sea-side crane) for loading and LC for carry-out must be overlapping. We can prove the following two properties:
Property 1: The interference probability between two cranes for the handling of export and import containers does not depend on the probability distribution of travel time.
Property 2: When there are transshipment containers, which are discharged from a vessel and then loaded onto another vessel in the same terminal, it will minimize the probability of interference to allocate a designated storage area only for transshipment containers at the end of the sea side of a block.

5 Analysis of the interference time between twin cranes

Let the travel time from the end of the land side (LE) to the destination (LD) of the LC (land-side crane) be X, while that from the end of the sea-side to the destination (SD) of the SC (sea-side crane) is Y, as shown in Figure 1. Suppose that the SC just starts from the end of the sea side of the block (SE) and the LC already started. Then, because the LC already started its operation, we assume that the LC has the higher priority than the SC in its travel, no matter where they are located and if their destinations are in the opposite direction.

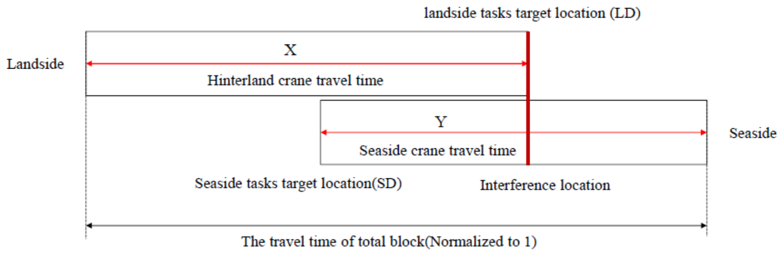

Fig.1: Top view of a single bay position in a twin crane conflict state

When calculating the travel time, the SC just starts from the end of the sea side, the important question is how much time will be wasted from the interference with LC which is already working within the block. The analysis of interference is necessary.

One of the most difficult problems in the estimation of cycle time for twin cranes is how to estimate the interference time of cranes during the handling operation. Twin cranes consist of SC and LC and they are traveling on the same rail, in which the interference between them during the operation is not avoidable.

Suppose that SC starts its travel from SE. Then, the SC will have to wait when the following conditions hold: LC is busy; the position of LD is at the right-hand side of SD ($X + Y > 1$) and LC cannot start its travel toward LE when SC arrives at LD. According to Figure 1, for the case when LC is doing a carry-out operation, SC arrives at LD earlier than the moment when LC finishes its operation at LD. Let the time already spent by LC be Z at the moment when SC starts its travel. So the remaining time until LC starts to move to the land side is

$$(X - Z) + p_{lb} + (p_{lb} + r_{lb})R_{re} \qquad (2)$$

which p_{lb} being the pick-up time from block for landside crane, r_{lb} is the release time from the block for the landside crane and R_{re} is the rehandling number. Also, the time for SC to arrive at LD is $1 - X$. Thus, SC may have to wait at LD if $(X - Z) + p_{lb} + (p_{lb} + r_{lb})R_{re} > (1 - X)$. Then, SC has to wait:

$$2X + p_{lb} + (p_{lb} + r_{lb}) \cdot R_{re} - 1 - Z. \qquad (3)$$

Similarly, an analysis of the waiting time under various operational procedures can be performed to derive the probability density function of the waiting time. Following thorough statistical analysis, the expected waiting times for both sea-side and land-side cranes can be obtained.

6. Conclusion

Based on the analysis of the cycle time of twin cranes, we expect to be able to estimate the performance of an entire block for a given set of design parameters, such as the block size, the speed of yard cranes, and the allocation of transfer tasks. The performance of a block may be the number of waiting trucks on the sea side as well as the land side, which are important service performance measures for the customers. It would be possible to compare different operation strategies, such as the storage location, the operation of the buffer zone within the block for relaying containers between twin cranes. The approach in this study can be extended to other types of yard crane systems for rapid evaluation of the performance without the support of the simulation study.

Keywords: Twin Cranes, Container Terminals, Performance Evaluation, Statistical Analysis

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Maritime Shipping

Tuesday, 27.08.2024, 12:00-13:30, Room 122

Chair: Branislav Dragović

An Insight of COVID-19-related Literature in Maritime Transport:
Branislav Dragović, Nenad Zrnić, Andro Dragović

Forecasting the Baltic Dry Index Using Machine Learning:
Tim Seemann, Pierre Bouchard, Stefan Voß

Strategic Fleet Planning in Collaborative Logistics in the Offshore Oil and Gas Industry: *Andreas Breivik Ormevik, Kjetil Fagerholt*

Tuesday, August 27, 12:00-13:30 h,
Session: Maritime Shipping

An Insight of COVID-19-related Literature in Maritime Transport

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Abstract. The present study aims to analyze the COVID-19-related literature published in journals. Through a systematic literature review, a comprehensive survey is conducted to capture the dimensions and issues of sustainability, resilience and public health discussed in the selected studies. The bibliometric software tools are used to obtain a satisfactory level of accuracy of the examination of datasets for science mapping. The findings of the impact of COVID-19-related literature on maritime transport were synthesized into ten research streams. These streams are considered to effectively analyze these impacts, the role of technology in implementing sustainable, resilient and public health-related strategies of each maritime transport subsystem during and after COVID-19. In that way, valuable knowledge is generated in short times to standardize and classify data sources and obtain findings through specified research streams. The collected, systematized and analyzed dataset contributes substantially to COVID-19-related literature on maritime transport. This study follows a unique approach, while the conducted dataset analysis enables the verifiability, transferability and further ap-plicability of this study framework to some other research areas.

Keywords: COVID-19-Related Literature Survey, Maritime Transport, Bibliometric Analysis

Tuesday, August 27, 12:00-13:30 h,
Session: Maritime Shipping

Forecasting the Baltic Dry Index Using Machine Learning

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Abstract. The Baltic Dry Index (BDI) is a pivotal indicator of dry bulk commodity freight rates and serves as an economic barometer. This study assesses the predictive accuracy of the BDI using machine learning models, including ARIMA, ARIMAX, XGBoost, and GRU. Extensive data collection from sources like Investing.com, Yahoo Finance, and the U.S. Energy Information Administration was conducted for the period from January 1990 to June 2023. Key factors influencing the BDI, such as global economic conditions, shipping supply, geopolitical events, fuel costs, and port congestion, were identified. The ARIMAX model, incorporating variables like MSCI, crude oil prices, and geopolitical risk indices, exhibited the highest accuracy with a Mean Absolute Error (MAE) of 39.06. However, accurately predicting BDI extremes remained challenging. The findings indicate the promise of machine learning in enhancing BDI prediction but highlight the need for model refinement and the incorporation of additional factors. Future research could enhance predictive accuracy by exploring hybrid modeling approaches, testing transformer models for time series prediction, and integrating sentiment analysis from respected magazines to better capture short-term trends.

Keywords: Forecasting, Baltic Dry Index, Machine Learning

Tuesday, August 27, 12:00-13:30 h,
Session: Maritime Shipping

Strategic Fleet Planning in Collaborative Logistics in the Offshore Oil and Gas Industry

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Abstract. Within the offshore oil and gas industry, designated platform supply vessels (PSVs) transport requested cargo from onshore supply bases to the offshore installations where extraction, processing and distribution of petroleum products takes place. The installations are controlled by different operators and serviced from different supply bases. In the current supply chain structure, each operator controls its own fleet of PSVs to service its own installations. In this paper, we study a strategic fleet planning problem for offshore logistics, allowing collaboration to take place among the operators and supply bases. We propose an integer programming model for solving the problem, where feasible candidate routes for the PSVs are generated as input. Three variants of collaborative logistics are examined, namely 1) sharing bases (for one operator), 2) sharing vessels (at one base), and 3) a combination of the two (i.e., full sharing). We perform computational experiments on a case study with 39 installations based on real data from four operators. To reduce the computational complexity, we first perform a clustering analysis where certain installations in close proximity to each other are grouped. The results show that base and operator sharing yield cost reductions of 12% and 5%, respectively. When combining both types of sharing, i.e., full sharing, the required fleet size of PSVs is significantly reduced and we observe savings of more than 22%. We also evaluate the potential for cost and fleet size reductions in different realistic scenarios. The results show that with reduced PSV sailing speeds due to worse weather conditions in the winter

season and with reduced demands, the benefits of collaborative planning increase further.

Keywords: Maritime Transportation, Collaborative Logistics, Fleet Sizing, Supply Vessel Planning

Berth Planning

Tuesday, 27.08.2024, 12:00-13:30, Room 123

Chair: Rob Zuidwijk

Dynamic Berth Allocation Policies in the Deep-Sea Terminals:
Rob Zuidwijk, Pieter van den Berg, Orkun Tunay, Debjit Roy

Optimizing Vessel Scheduling and Berth Allocation in Constrained Maritime Environments:
A Metaheuristic Approach: Christian Bierwirth, Robert Burdett, Paul Corry

Risk or Slack – How to Tackle Uncertainty in Berth Allocation Planning: *Lorenz Kolley, Kathrin Fischer*

Tuesday, August 27, 12:00-13:30 h,
Session: Berth Planning

Dynamic Berth Allocation Policies in the Deep-Sea Terminals

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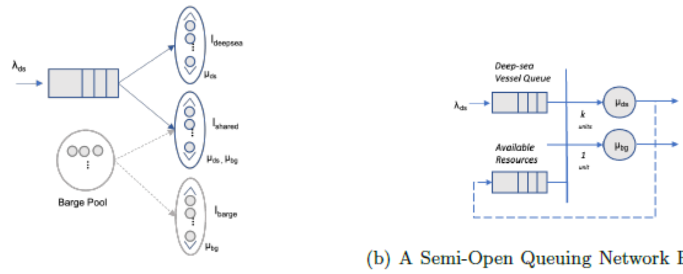
Introduction

In global seaports, hinterland network connectivity is dominated by road and rail transportation. However, inland waterways have emerged as a critical component of regional logistics connectivity, prominently in Rhine-Danube Corridor, Yangtze River, Mississippi River. The inland waterway networks serve as the gateway to the global trade networks for landlocked industrial regions. Ports that are well positioned along these networks also play an important role in the global trade logistics, such as the Port of Rotterdam and the Port of Shanghai. In particular, due to their cost-effectiveness and lower carbon footprint, inland waterways are poised to play a pivotal role in the decarbonization of the maritime industry. However, the nature of hinterland operations in these ports is different from the ports that are only connected to the hinterland by road and rail networks. Unlike road and rail transportation, inland waterway barges must compete for handling capacity at seaside terminals. This creates a trade-off between the deep-sea vessel handling capacity and barge handling capacity while a certain level of barge throughput is needed to ensure the efficiency of hinterland operations for the terminal operators and the efficiency of the hinterland network for the port authorities. The ocean-going deep-sea vessels with capacities of more than 20,000 TEU are primary sources of revenue for the terminal operators while in most cases there is no financial or contractual relationship between the barge operators and the terminal operators. Both sides are usually paid by the shipper. This leads to the prioritization of deep-sea vessels by the terminal operators, as the service level requirements only exist for the deep-sea vessels. As these deep-sea vessels evolve into mega vessels that require days to be handled, ports started to face more bottlenecks with congestion and long waiting times [4]. The bottlenecks caused by increasing container volumes also lead to congestion in the road networks. Congestion management and prioritization policies directly influence the trade-off between the deep-sea vessel service levels and barge throughputs. In this research, we would like to understand how to balance the deep-sea vessel waiting times and barge throughput in container terminals. The research will contribute to the optimization in maritime transportation literature which is already scarce in inland waterway studies. The research will extend the widely studied berth allocation problem by incorporating modal shift and sustainability objectives [1]. The research will also methodologically contribute to the literature of semi-open queuing networks and the class of queuing systems that



(a) Overarching Queuing System

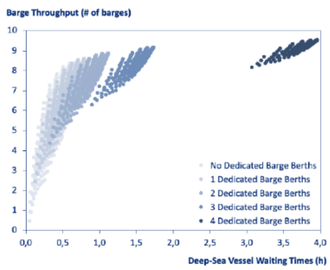
(b) A Semi-Open Queuing Network Equivalent of A Single Shared Berth

are solvable by matrix-geometric methods.

Fig.1: A Queuing Network Model for A Deep-Sea Terminal

2 Methodology

In order to demonstrate the long-term implications of different terminal design settings and congestion management policies, we will model the deep-sea terminal as a queuing system. The system serves two classes of customers, deep-sea vessels and barges. To capture the effect of different vessel sizes, we take berth spaces that the vessels occupy as the servers of the system. In the system, there are three groups of servers, i.e. dedicated deep-sea berths, shared berths and dedicated-barge berths. Each berth takes one deep-sea vessel or multiple barges which means each server will have a capacity of either serving one deep-sea vessel or multiple barges. The arriving deep-sea vessels are berthed in a dedicated deep-sea berth, if there is a berth available. If no berth is available in the dedicated deep-sea berth, deep-sea vessels will have non-preemptive priority in the shared berth space. The illustration of the queuing model can be found in Figure 1a. While the dedicated berths act as M/M/c queuing systems, the shared berths act as semi-open queuing networks with heterogeneous resource requirements as illustrated in Figure 1b. Semi-open queuing networks with homogeneous resource requirements have numerical solutions with aggregation, network decomposition, parametric decomposition, performance bounds and a matrix-geometric method [3]. In this research, we extend the solution of semi-open queuing networks to heterogeneous resource requirements with the matrix-geometric method and we show that for the overarching queuing system depicted in Figure 1a, the matrix-geometric method is still a valid solution method as the matrix geometric property in the system is preserved [2]. We show the solution of this queuing system under varying settings and priority protocols. Given the pareto-efficiency frontier of deep-sea vessel waiting times and barge throughputs, constructed for various terminal heuristics, we later develop and test dynamic berth allocation policies and smart heuristics to show the optimality gap of the current terminal heuristics.



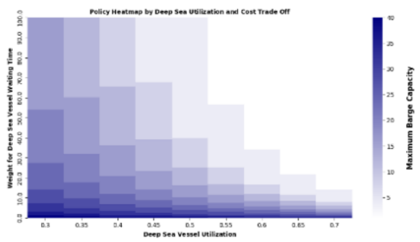


Fig. 2: Performances Clustered Based on the Number of Dedicated Barge Berths For 50% Deep-Sea Vessel Utilization

Fig. 3: Maximum Number of Barges Accepted Given theWeight of the Deep-Sea Vessel Waiting Time For Varying Deep-Sea Vessel Utilizations

3 Conclusions

We run a case study for our model based on the design of the ECT Delta Terminal at Maasvlakte II in the Port of Rotterdam. Our numerical experiment shows that many terminal heuristics perform under the pareto-efficiency frontier. We construct the pareto-efficiency frontier for barge throughputs and deep-sea vessel waiting times given the obtained steady-state probabilities for the full set of terminal heuristics. We show that the number of dedicated barge berths play an important role for the clustering of the policies. The clusters show that having shared berths bring more flexibility and cover a wider range on the pareto frontier as illustrated in Figure 2. Given the weight of the deep-sea vessel waiting time, we also obtain the best policy on the pareto-efficiency frontier from the tangents of the curve. From the best policy on the frontier, aside from the dedicated barge berths, we can obtain the maximum number of barges allowed to the berths when there is no deep-sea vessel in the terminal for different deep-sea vessel utilization rates as given in Figure 3.

Keywords: Port Logistics, Inland Transportation, Queueing Networks

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Tuesday, August 27, 12:00-13:30 h,
Session: Berth Planning

Optimizing Vessel Scheduling and Berth Allocation in Constrained Maritime Environments: A Metaheuristic Approach

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Abstract. This study investigates an optimization challenge in maritime operations: scheduling vessel movements and allocating berths within a constrained port environment. Narrow shipping channels can limit port capacity by restricting the ability of ships to safely pass each other. To address this, we explore an integrated approach to vessel scheduling and berth allocation. This computationally complex problem is known to be difficult to solve exactly, especially for large-scale scenarios. Here, we present the application of two established metaheuristic algorithms, Simulated Annealing (SA) and Evolutionary Search (ES), to tackle this challenge. Our novel contribution involves the integration of a priority-based sequencing scheme and the customization of existing perturbation techniques specifically tailored to the problem. Through a comprehensive computational analysis, we demonstrate that SA consistently outperforms the ES algorithm. Notably, within a ten-minute time limit, SA exhibits superior solution quality compared to a high-performance commercial solver, CPLEX, even when leveraging 32 CPU cores. This highlights the efficiency and effectiveness of SA in this specific maritime optimization problem.

Keywords: Berth Allocation, Channel Scheduling, Priority-based Sequencing Scheme

Tuesday, August 27, 12:00-13:30 h,
Session: Berth Planning

Risk or Slack – How to Tackle Uncertainty in Berth Allocation Planning

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Abstract. The aim of berth allocation planning is to derive conflict-free vessel assignments to the quay of a container terminal. An important objective of terminal operators in the context of this problem is to provide the best possible customer satisfaction to the shipping companies, i.e., especially by offering short waiting times. The berthing schedule resulting from solving the corresponding Berth Allocation Problem (BAP) consists of the berthing times and positions of all vessels that are expected to arrive within a certain timeframe; these vessels are scheduled according to their respective arrival and handling times. However, both these times are uncertain due to different influences, e.g., weather, technical breakdowns or maintenance.

Deviations from the planned arrival and handling time lead to delayed vessel departures, which cause waiting time for the succeeding vessels and can ultimately result in conflicts that may impede the schedules' feasibility. Hence, updating or re-planning berthing schedules can become necessary, but this is costly and may be impossible when a plan is already under execution. Therefore, the aim of this work is to derive robust berthing schedules that enhance the schedules' stability by considering uncertainty already in the planning phase and, thus, are resistant to uncertainties, especially of handling times. A berthing schedule is considered robust here if it remains feasible while executing the schedule even though the actual handling times deviate from the planning.

In the literature, two main strategies can be distinguished regarding the development and use of time buffers for mitigating uncertainty in the vessels' arrival and handling times: Maximizing the slack (buffer) between each pair of succeeding vessels or

considering a predetermined individual time buffer in the optimization of the berthing schedule. Both approaches are implemented for the continuous berth allocation problem and solved considering estimated handling times for approaching vessels based on their historical AIS data at real container terminals in Denmark, i.e. past handling times of the same vessels. The results are evaluated and compared in this work from an ex-post perspective using the actual handling times from the AIS data for that port approach. In particular, schedules' robustness is considered, measured through the number of vessel conflicts at the quay and the time spent by vessels in conflict according to the respective schedule.

Keywords: Berth Allocation Problem, Uncertainty, Robust Optimization, Maritime Logistics

Port Digitalization and Automation

Tuesday, 27.08.2024, 14:30-16:00, Room 121

Chair: Ikyeong Moon

A Dynamic Pickup-and-Delivery Problem with Recharging for Autonomous Delivery Robots in an Airport Terminal:
Joonhwa Jeong, Ilkyeong Moon

Pricing and Empty Container Repositioning Strategy for a Container Sharing System*:*
Junseok Park, Ilkyeong Moon

Development of a Novel QC Work Congestion Index to Enhance Accuracy in Predicting Ship Operation Time:
Daesan Park, Taeeon Noh, Yohan Koo, Hyeonjik Lee, Hyerim Bae

Tuesday, August 27, 14:30-16:00 h,
Session: Port Digitalization and Automation

A Dynamic Pickup-and-Delivery Problem with Recharging for Autonomous Delivery Robots in an Airport Terminal

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1. Introduction

With the expansion of the delivery market during the COVID-19 pandemic, maintaining a high quality of service while satisfying increased demand has become a significant operational challenge. The implementation of autonomous robots for last-mile delivery is proposed as an efficient operational solution facilitated by advancements in self-driving technology and artificial intelligence. Initially utilized for material handling in warehouses, relaxed regulations on pedestrian road operation have led to a significant expansion of autonomous robot applications, particularly in delivery. Autonomous delivery robots (ADRs) have emerged and increasingly assume a larger share of the last-mile delivery market.

The use of autonomous delivery robots offers undeniable competitive advantages over human drivers. By eliminating inherent human limitations such as hour-of-service constraints and fatigue issues, ADRs ensure a more efficient and reliable delivery process. The integrated control of order routing in ADRs guarantees optimal results, showing a contrast to human-driven systems where route choices are often subjective. Moreover, ADRs demonstrate superior adaptability to unexpected events, facilitating smoother communication and system improvements between dispatchers and robots compared to human-driven deliveries.

There have been extensive studies on the dynamic pickup-and-delivery problem (DPDP) with various strategies and circumstances. Jun and Lee [1] considered time windows and multiple depot locations with the use of green vehicles in the operation. Arslan et al. [2] minimized operational costs during service, while Cheng et al. [3] emphasized the customer side and maximized the service level.

In this study, we seize the new-found opportunity presented by ADR deployment to revolutionize dispatching decisions throughout the delivery process. We propose an innovative reassignment strategy that dynamically reallocates previously allocated orders when new orders arrive. Additionally, we introduce a cutting-edge battery management tactic designed for operational use. The extensive experiment results confirm the superior performance of these two innovative solution approaches.

2. Methodologies

We introduce a dynamic pickup-and-delivery problem using autonomous robots (DPDP-AR). The DPDP-AR comprise a set of orders that a fleet of ADRs needs to serve. The time horizon is finite, and a set of nodes represents locations visited during delivery. An order comprises four characteristics: order time, deadline, pickup restaurant, and delivery location. The decision epoch occurs each time an order is submitted. At every decision epoch, a decision is made based on the decision state at the time. The elements that constitute the decision state are the earliest available time and battery level of each ADR and the list of orders dispatched earlier but not yet started on deliveries. The earliest available time of an ADR indicates the fastest time the ADR can begin delivering a new order after finishing all the pre-assigned deliveries.

In this research, we implemented a partial recharging approach for battery management named (BL, RL) policy. This strategy is similar to the established (r, Q) policy commonly employed in inventory management. Analogous to the (r, Q) policy, where a quantity of Q is ordered whenever the inventory level reaches r, our proposed approach involves charging a predefined quantity RL if the battery level falls below a specified threshold BL after completing an order.

To solve the problem with orders arriving during the time horizon, we devised a rolling horizon-based reassignment policy in which orders that arrived and were assigned previously but have not yet commenced delivery are assigned again in the present time. As a result of reassignment, future operations are expected to benefit from increased flexibility. More efficient solutions can be found as more orders are assigned in each reassignment.

3. Results

We present the results of the experiment with the results of the reassignment policy demonstrated through comparison with two myopic policies. We conducted experiments on the circumstances of the ADR-based food service at Incheon International Airport. The cost function and number of rejections are evaluated for reassignment policy, myopic 1 policy, and myopic 2 policy. The experiment was conducted on three cases of demand: low, moderate, and high. In low-demand cases, the average of the cost function for the reassignment policy was 702.87, which is significantly lower than the cost function of the Myopic 1 and Myopic 2 policy with 951.42 and 743.83, respectively. The reassignment policy showed a significant decrease in the cost function of moderate-demand and high-demand cases. The number of rejections did not vary much by algorithms in the low-demand case. However, the reassignment policy resulted in a reduction of more than 20% compared to the two myopic policies in moderate-demand and high-demand cases. We can conclude that the reassignment policy showed a significant decrease in the cost function and the number of rejections compared to two benchmark policies.

4. Conclusion

In this study, we introduced a solution methodology to tackle challenging situations concerning the pickup-and-delivery problem. We formulated a novel DPDP-AR problem incorporating ADR features and presented a reassignment policy and mathematical formulation derived from the static model. Additionally, we proposed practical battery management strategies. Experiment results confirmed the enhanced solution quality of the reassignment policy compared to current practices.

For future research, we aim to broaden the problem scope with more practical applications. This includes incorporating stochastic order arrivals and order reservations into the model. We plan to devise policies capable of managing pre-announced and stochastic orders and explore the potential of adjusting ADR speed as a decision variable considering varying battery discharge rates. Anticipatory policies based on demand forecasts and the application of approximate dynamic programming and reinforcement learning methodologies are also under consideration for future decision-making processes.

Keywords: Dynamic Pickup-and-Delivery Problem, Autonomous Delivery Robot, Battery Recharging Strategy

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Tuesday, August 27, 14:30-16:00 h,
Session: Port Digitalization and Automation

Pricing and Empty Container Repositioning Strategy for a Container Sharing System

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1. Introduction

Global trade mainly occurs through maritime transportation, which accounts for 85% of global trade, yet an imbalance exists in intercontinental cargo volumes. When freight is transported from export-oriented nations in Asia to import-focused regions like North America and Europe via containers, some of these containers should return empty or underutilized. Consequently, the retrieval and repositioning of empty containers are essential but incurring substantial costs for their owners, leading to a retrieval rate below 100% and exacerbating intercontinental container imbalances. The COVID-19 pandemic caused container imbalances due to various factors, resulting in surging freight rates and logistical crises, emphasizing the importance of empty container repositioning.

Containers are divided into carrier-owned containers and shipper-owned containers, further categorized into directly purchased or leased from leasing companies. Container leasing offers advantages such as flexibility in response to demand fluctuations, avoidance of capital fixation, and reduction in ancillary costs, with various lease types including long-term, short-term, round-trip, and one-way leases. However, research on one-way leasing, which allows freedom in container retrieval to carriers, remains insufficient.

Lee et al. (2012) investigated empty container repositioning policies based on inventory management methods to address uncertain demand. Specifically, they considered the (T, S) policy as a periodic inventory review model and utilized the non-linear programming and infinitesimal perturbation analysis-based gradient to resolve the problem. Lu et al. (2020) simultaneously considered pricing decisions and empty container repositioning from the perspective of carriers. However, the analysis was limited to only two ports, and only round-trip container leasing was considered. Lu et al. (2021) studied the optimal pricing and vehicle relocation in a one-way carsharing system. While similar to the problem situation in this study, the difference lies in the shorter leasing duration and relocation/repositioning lead time compared to containers. We consider a container sharing system to address container imbalances. Through this research, the profitability and effectiveness of the container sharing system were analyzed to determine, if it could successfully resolve container imbalance issues and to design a rational one-way container leasing system to alleviate shipping companies' financial burdens, thus proposing a new logistics paradigm.

2. Methodologies

Utilizing non-convex mixed-integer quadratic programming, we analyze the effectiveness of a one-way container leasing system based on the sharing economy. Specifically, we formulate models from the perspective of container leasing companies to determine optimal leasing prices and empty container repositioning plans. However, considering the uncertainty in demand, we propose practical rule-based strategies, since achieving optimal decision-making in real-world scenarios is implausible. Based on the derived optimal prices, we propose mathematical models representing rule-based empty container repositioning strategies based on inventory management models using mixed-integer linear programming. Moreover, we compare the performances of the proposed rule-based strategies with the optimal decision through simulations, ensuring a robust adaptation to uncertain demand scenarios considering various intercontinental container imbalance levels and demand fluctuation levels. Additionally, we evaluate the performance of the container sharing system under different scenarios, comparing the number of containers to the average demand. We analyze the profitability of the system, considering revenue and costs associated with empty container repositioning and container storage/maintenance, as well as the regional changes in container quantities, to provide insights into resolving container imbalances. Experiments were conducted with FICO Xpress version 8.12.

Empty Container Repositio-ning Model	1. Optimal decision 2. (T, S) policy 3. (r, Q) policy 4. (s, S) policy
Demand	1. Stable 2. Fluctuating
Intercontinental imbalance	1. Mild (balanced) 2. Severe (imbalanced)
The # of containers	1. Insufficient 2. Adequate 3. Ample

Table 1. Type of situations

3. Results

In this section, we present the results of our experiments, i.e., the total profits and quantities of empty container repositioning for each case.

	Stable						Fluctuating					
	Balanced			Imbalanced			Balanced			Imbalanced		
	Ins.	Ade.	Amp.	Ins.	Ade.	Amp.	Ins.	Ade.	Amp.	Ins.	Ade.	Amp.
Opt.	149,524 / 0.9	168,843 / 0	183,555 / 0	109,325 / 0	130,197 / 0	147,960 / 0	147,403 / 4.7	167,436 / 0	182,159 / 0	108,450 / 0	129,224 / 0	146,857 / 0
(T,S)	145,844 / 0	147,618 / 1.9	142,936 / 0	91,352 / 28.9	93,952 / 0	94,226 / 0	139,021 / 0	143,512 / 22.1	140,721 / 0	89,840 / 17.1	92,718 / 0	93,193 / 0
(r,Q)	149,522 / 0	168,843 / 0	183,555 / 0	10,9325 / 0	13,0197 / 0	147,960 / 0	147,395 / 0	167,436 / 0	182,159 / 0	108,450 / 0	129,224 / 0	146,857 / 0
(s,S)	149,345 / 0	168,416 / 0	182,985 / 0	10,9223 / 0	13,0071 / 0	147,802 / 0	147,372 / 0	166,840 / 0	181,389 / 0	108,430 / 0	129,079 / 0	146,622 / 0

Table 2. The total profits and quantities of empty container repositioning

4. Conclusions

In this research, we demonstrated the effectiveness of the container sharing system and designed a rational one-way container leasing system to alleviate intercontinental container imbalances and ease the burden on shipping companies. We analyzed the profitability of the one-way contract-centric container sharing system and proposed its sustainability for successful adoption. We aim to reduce logistics waste by optimizing deadheading container transportation and lay the groundwork for establishing eco-friendly maritime logistics networks.

Due to the lack of research integrating one-way leasing contracts or the sharing economy with container leasing, this study anticipates a surge in related research activities, aiming to prevent logistical crises like those aroused during the COVID-19 pandemic by resolving intercontinental container imbalances and easing the burden on shipping companies, thereby promoting growth in the container spot market.

Future research could be linked to operational optimization studies that consider container sharing systems from the perspective of carriers. By analyzing the effects of reducing the number of owned containers on liquidity securement and ancillary cost reduction, such research can demonstrate the superiority of those systems, contributing to cost alleviation for shipping companies, enhancing logistics efficiency, and fostering the development of maritime logistics markets.

5. Acknowledgments

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (Ministry of Science and ICT) [Grant No. RS2023-00218913].

Keywords: Container Sharing System, Sharing Economy, One-way Leasing, Empty Container Repositioning, Pricing

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Tuesday, August 27, 14:30-16:00 h,
Session: Port Digitalization and Automation

Development of a Novel QC Work Congestion Index to Enhance Accuracy in Predicting Ship Operation Time

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Abstract. The problem of port efficiency is becoming more pronounced due to the increase in international trade driven by the growth of the e-commerce market, leading to greater port complexity. Specifically, the uncertainty surrounding ship operation hours reduces berth productivity and port efficiency, causing economic losses. To address this uncertainty, previous studies have proposed predicting ship operation hours based on static variables such as berth planning and ship specifications. However, the recent surge in trade volume has exacerbated the congestion within ports, highlighting the need for predictions that account for dynamically changing port congestion. This study introduces the QC Work Congestion Index, which quantifies congestion between Quay Cranes (QC) and Yard Trucks (YT) in a Queueing system. By utilizing this index, this study aims to enhance the accuracy of predicting ship operation hours and improve port efficiency through better ship scheduling and decision-making support.

Keywords: Quay Crane Work Congestion Index, Queuing System, Ship Operation Time, Port Productivity

Manufacturing, E-Commerce and Last-Mile Delivery

Tuesday, 27.08.2024, 14:30-16:00, Room 122

Chair: Lijun Ma

Hybrid Flow Shop Scheduling with Workforce Assignment for Additive Manufacturing:
Benedikt Zipfel, Nadine Schiebold

Sequentially Sponsored Products and Off-Amazon Advertising Optimization for Etailers:
Yina Ning, Yangyang Xie, Houmin Yan, Lijun Ma

Last-Mile Delivery Route Optimization Considering Collection of Reusable Bags:
Sangjun Yoon, Gwang Kim, Youngchul Shin

Tuesday, August 27, 14:30-16:00 h,
Session: Manufacturing, e-Commerce and Last-Mile Delivery

Hybrid Flow Shop Scheduling with Workforce Assignment for Additive Manufacturing

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Abstract. Compared to traditional manufacturing technologies, additive manufacturing (AM) excels in the efficient production of increasingly complex items without the need for additional production resources.
Although created directly from digital model data, items printed by AM still require manual post-processing. Consequently, effective planning must encompass both the scheduling of items to be printed and the allocation of human resources. This study addresses the integration of scheduling and workforce assignment in AM environments. We consider a two-stage hybrid flow shop production system, with the first stage focused on printing and the second on post-processing, taking into account machine availability, skill levels, and shift patterns. By employing a decomposed solution approach, we solve the individual sub-problems sequentially, achieving high-quality solutions with small computational effort. Finally, we provide important managerial insights revealing that expanding post-processing skills can reduce the makespan by 13 %, while carefully selecting the workforce which decreases the makespan by up to 22 %.

Keywords: Hybrid Flow Shop Scheduling, Workforce Assignment, Additive Manufacturing

Sequentially Sponsored Products and Off-Amazon Advertising Optimization for Etailers

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Abstract. A lot of logistic studies utilize the framework of the Multi-Armed Bandit (MAB) problem. This study explores the application of MAB in e-commerce platforms, and the results can also be applied to logistic planning problems. The Sponsored-Products (SP) advertisement is a popular way for promoting products on Amazon. Etailers can choose and pay for specific keywords to secure ad placements for their products. These keywords are the ones that shoppers are likely to search for when looking for products on Amazon. To improve the efficiency of SP ads, etailers with a large catalogue of products often create ad groups for products with similar attributes. An ad group consists of a set of products and a set of keywords, and all the products in the ad group share the same keyword set. Etailers may also choose to link to external websites for advertising their products and attracting consumers, which is called off-Amazon (OA) ads. This study focuses on the sequential SP and OA ads optimization problem for etailers. Practically, many etailers set sales targets for products as manufacturing and logistics are planned ahead of time. Hence, we consider that the objective of the etailer is to minimize the expected long-run average cost associated with advertising and the cumulative deviation between the sales target and actual sales. When the mean of the sales number per unit time (i.e., sales rate)

for each product is known, we characterize the optimal sequential SP and OA advertising policy (abbreviated as SSPOA policy) for products in an ad group, which is of one threshold type. However, in reality, etailers may not know the exact mean of sales rates, and therefore the SSPOA problem becomes a controlled Markovian MAB problem with an exploration-exploitation trade-off . We devise a Thompson sampling-based SSPOA algorithm to balance exploration and exploitation adaptively via sampling and updating processes. Moreover, $\tilde{O}(\sqrt{T})$ we prove that the regret bound of the proposed algorithm is ,where T is the number of time periods. We illustrate the pipeline of our model in Figure 1. At the beginning of each period, the etailer selects a keyword set for products in the ad group with SP advertisement, and then she continuously controls the OA advertisement for each product during the period. Until the start of the next period, the etailer selects a keyword and continuously controls the OA ads for each product during the period, repeating this cycle.

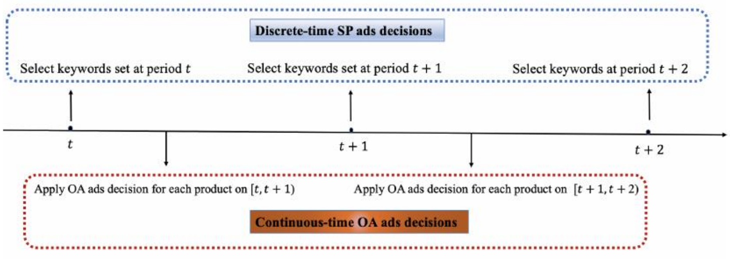

Figure 1: The flow of the decision sequence

The contributions are summarized as follows. Firstly, we investigate the controlled Markovian MAB problem where the states evolve as a Markovian Decision Process after an arm (i.e., an SP keyword set) is selected in each period, while existing literature (Tekin and Liu, 2011; Ronald et al., 2014; Niño-Mora, 2023) studies the uncontrolled Markovian MAB problems in which the states evolve as a Markovian chain. For our controlled Markovian MAB problem, the control policy (i.e., OA ads control policy) during the current period relies on the parameters estimated from previous-period samples and affects the learning process and states evolution in succeeding periods. As a result, the process endogenizes

the interaction between the arm selection, OA ads control policy, and parameter estimation, which sets our problem apart from the

existing uncontrolled Markovian MAB problems and adds to its complexity. Secondly, we develop Thompson-sampling-based SSPOA algorithms to learn the unknown parameters of each arm (i.e., the expected high
and low sales rates of all N products for each keyword set) while simultaneously minimizing the corresponding long-run average cost. When designing the algorithms, we need to consider the interaction between the arm selections and OA ads decisions, whereas existing literature separately considers these two types of decisions (Agrawal and Goyal, 2012; Ronald et al., 2014; Kim, 2017; Banjević and Kim, 2019). Thirdly, when evaluating the regret bounds of the proposed algorithms, we need to incorporate the regret from implementing the estimated control policy in addition to the regret from selecting non-optimal arms in the existing literature (Tekin and Liu, 2011; Ronald et al., 2014; Niño-Mora, 2023). Moreover, in our model, even the regret from selecting non-optimal arms is different from previous studies because we need to additionally consider the impacts of choosing non-optimal arms on subsequent control policies and states. Furthermore, each arm in our model has multiple unknown parameters that may not be updated when the arm is chosen. While in the classical model (e.g., Agrawal and Goyal 2012), each arm has only one unknown parameter (i.e., the expected reward of the arm), and the parameter is updated as long as the arm is selected. Therefore, we cannot adapt the analysis of the classical MAB problem to bound the expected number of choosing non-optimal
arms. Consequently, we cannot utilize the method in existing literature to derive the regret bounds for our proposed algorithms. To deal with these challenges, we propose a new approach for characterizing the regret bounds through introducing the notion of a transition policy, which enables us to measure the regret of selecting non-optimal arms through bounding the expected cost difference between implementing the transition policy and implementing the optimal policy, and measure the regret from applying a estimated control policy through bounding the expected cost difference between implementing our proposed TS-based policy and the transition policy.

We conduct the numerical experiments and show the regrets of different algorithms. In Figure 2, the height of each bar represents the mean regret of each algorithm after 100 trials, and the upper and lower error bars represent the upper and lower bounds of the 95% confidence interval. From Figure 2, we find that both the

average regret-per-unit time and the standard deviation of the regret-per-unit time for each algorithm
decrease over time. Furthermore, the standard deviations of the four algorithms are similar when T is large and the average regret-per-unit time of our TS-based SSPOA algorithm is smaller than those of the other three algorithms, which implies that the TS-based SSPOA algorithm outperforms classical algorithms. For example, when T = 600, the average regret of our TS-based SSPOA algorithm is 17%, 54%, and 42% of that of the UCB algorithm, the 0.05-greedy algorithm, and the 0.1-greedy algorithm, respectively.

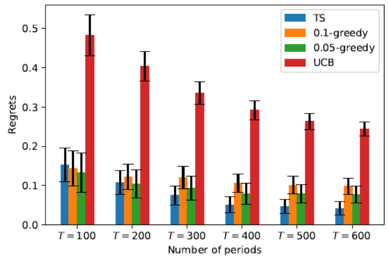

Fig. 2: Comparison of the regrets of various algorithms

Keywords: Sequential Sponsored-Products (SP) and off-Amazon (OA) Advertising, Keywords Selection, Controlled Markovian Multi-Armed Bandit (MAB) Process, Thompson Sampling, Regret Bound Analysis

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Tuesday, August 27, 14:30-16:00 h,
Session: Manufacturing, e-Commerce and Last-Mile Delivery

Last-Mile Delivery Route Optimization Considering Collection of Reusable Bags

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Abstract. The rapid growth of the e-commerce market has led to an increase in logistics volumes and significant use of disposable parcel boxes. To address environmental issues, various e-commerce companies have introduced reusable bags to minimize the use of disposable parcel boxes. However, these reusable bags must be collected from the delivery drivers, complicating the drivers' routes in terms of the decision-making process. In this research, we propose a mathematical model based on the vehicle routing problem, considering the routes for the collection of reusable bags and customer demands. Additionally, we develop an efficient heuristic algorithm to tackle the high computational complexity of the proposed optimization model. The results of numerical experiments show that our heuristic algorithm provides solutions of good quality with short computation times.

Keywords: E-Commerce, Last-Mile Delivery, Vehicle Routing Problem

Sustainable Maritime Logistics

Tuesday, 27.08.2024, 16:30-18:00, Room 121

Chair: Kap-Hwan Kim

A Semi-supervised Learning Imputation Model for Automatic Identification System Data:
Jaehyeon Heo, Dohee Kim, Sekil Park, Sunghyun Sim, Hyerim Bae

Spatial-Temporal Analysis of Ship Collision Risk:
Suhyeon Jo, Dohee Kim, Sekil Park, Sunghyun Sim, Hyerim Bae

Long-Term Forecasting of Pollutant Emissions in the Arctic Ocean Based on Cross-Dimensional Dependency Network using Arctic Ship Traffic Data:
Sunghyun Sim, Younghwi Kim, Ki-Tae Kim, Hyerim Bae

Tuesday, August 27, 16:30-18:00 h,
Session: Sustainable Maritime Logistics

A Semi-supervised Learning Imputation Model for Automatic Identification System Data

Jaehyeon Heo[1], Dohee Kim[1], Sekil Park[2], Sunghyun Sim[3], Hyerim Bae[1a]

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Abstract. The quality of Automatic Identification System (AIS) data is weakened as a result of geographical, environmental, and technical constraints. The presence of these constraints hinders the reliable collection of AIS data, leading to a decline in data quality, particularly evident through the occurrence of missing values. Missing values in AIS data occur sporadically and pose a challenge when it comes to replacing them. However, the frequently employed approach of Supervised Learning model has limitations in dealing with such irregular occurrences. Therefore, in this study, an imputation method utilizing Semi-Supervised Learning Imputation (SSLI) model has been introduced. Additionally, a novel loss function has been proposed for SSLI. The method proposed in this paper shows better performance in replacing missing values, especially in situations when the pattern is complicated, by using information from both previous and subsequent periods during the learning process. The imputation model proposed in this study has the potential to improve the quality of AIS data for ships with complex patterns. This expected benefit extends to other research applications, enhancing its utility across a broad spectrum of disciplines.

1 Introduction

Data collected from the Automatic Identification System (AIS) includes dynamic and static information about sailing ships [1]. AIS data, which serves numerous purposes, has various challenges

due to device faults, channel congestion, and communication mistakes [2]. A variety of difficulties include inaccurate data, missing values, abnormal entries, and duplicate records [3]. The presence of missing values among these difficulties hinders the process of conducting reliable analyses [4]. Therefore, the imputation of missing values in AIS data is a challenging topic.
In this study, a semi-supervised learning Imputation (SSLI) model has been presented to improve the quality of AIS data. The SSLI model is designed to overcome the limitations of traditional supervised learning models. It consists of a network architecture that includes both forward and backward models. This combination enables learning in both directions. In addition, a unique loss function is utilized to facilitate dual-directional learning. The application of the SSLI model for replacing missing values in AIS data results in an exceptional performance, especially in situations with complex trajectories.

2 Methodology

As previously stated, methods for replacing or predicting missing values in AIS data frequently depend on network architectures that utilize forward learning. Although these approaches are effective for handling missing values that occur regularly or follow consistent patterns, they encounter challenges when dealing with the irregular occurrence of missing values in actual datasets [5]. Hence, applying semi-supervised learning is more advantageous in addressing these uncommon cases. In order to address this challenge, this paper introduces SSLI using network architecture which consists of a dual-directional model.

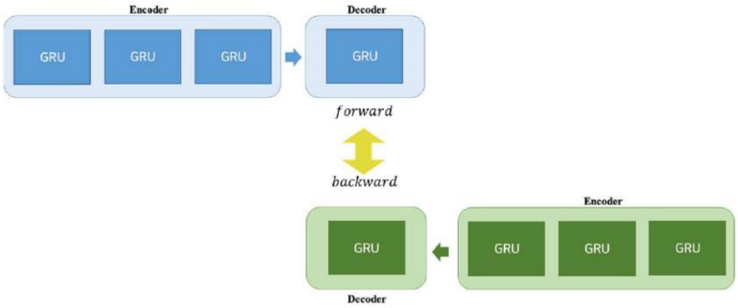

Fig. 1. Architecture of the SSLI Model

Figure 1 depicts the comprehensive structure of the suggested methodology. The method we propose performs imputation by employing dual-directional prediction, applying both the forward and backward models in combination. The forward and backward model have distinct prediction orientations; however, their structures are identical. Each direction of the model is structured as a Sequence-to-Sequence (seq2seq) model, utilizing a combination of an encoder and decoder that incorporates the Gated Recurrent Unit (GRU) model.

The proposed model's advantage resides in its ability to define the loss that the model learns. The model's learning process is divided into two categories: points with complete data and points with missing values. Loss is defined as the discrepancy between the predicted value and the actual value, as indicated by Equation (1). This definition assumes that there are no missing values at the place where the actual value exists.

$$\mathrm{L}_{real} = MAE\left(x_{predict}^{forward},\ x_{real}\right) + MAE(x_{predict}^{backward}, x_{real}) \tag{1}$$

Conversely, the actual value is absent at the location where missing values are present. Thus, at this point, the loss is specified in a manner that ensures that the learning directions of the forward and backward models are comparable. In order to align the predictions of the forward and the backward model, the discrepancy between their anticipated values is utilized as a loss function. The lambda value is then modified to regulate the influence of this discrepancy on the model's learning process. Equation (2) represents the expression of the loss.

$$\mathrm{L}_{missing} = \lambda \times MAE\left(x_{predict}^{forward}, x_{predict}^{backward}\right) \tag{2}$$

A SSLI is employed to learn an imputation model, which is trained using the loss defined in equations (1) and (2). The proposed model is supported by the architecture of the dual-directional model, which allows for an imputation that accurately represents the movement characteristics of the ship.

3 Experiment

The study employed AIS data obtained from around 300 ships navigating close to the Port of Busan, Korea. During the preprocessing phase, an experiment was carried out to categorize each ship's path into three levels of complexity (simple, complex, and very complex). The accuracy of imputation was then assessed by adjusting the missingness rate to 30%, 50%, and 70%. The experiment compared the performance of different models, including linear and statistical-based KNN, MICE, and EM algorithm imputation methods, as well as the deep learning-based BRITS model. Table 1 displays the outcomes of imputation performance when the proportion of missing values is 30%.

Performance measure		custom		MSE	custom
Complexity	Model	Latitude	Longitude	SOG	COG
Complex	EM	27.7156	31.5366	31.4627	77.1251
Complex	KNN	41.2018	39.3504	41.9456	81.1222
Complex	BRITS	15.3481	18.5629	22.7167	56.3796
Complex	MICE	2.3975	2.2448	11.0799	44.2574
Complex	**SSLI**	**1.5508**	**1.4267**	**4.3420**	**27.4650**

Table 1. Experimental results when the path is complex and the missingness rate is 30%.

4 Conclusion

This study presents a novel SSLI model that has been designed to effectively handle missing values in AIS data. The model outperforms other approaches in terms of performance. The proposed SSLI framework overcomes the limitations of supervised learning methods for AIS data imputation by utilizing a novel loss function. Comparative experiments show that the proposed approach performs better than both supervised learning model and typical imputation methods, especially in cases with complex data patterns. The occurrence of irregular missing data patterns presents difficulties for supervised learning models and traditional imputation approaches, thus constraining their predictive accuracy for missing values in AIS data. On the other hand, the approach outlined in this study is particularly effective at accurately replicating data patterns. By enhancing the quality of AIS data, we anticipate improvements in various research endeavors relying on this data. However, future research efforts should explore methodologies such as federated learning to enhance the current model, given its high computational demands.

Acknowledgments

This research was supported by Korea Research Institute of Ships and Ocean engineering through a grant from Endowment Project of "Development of Open Platform Technologies for Smart Maritime Safety and Industries" funded by Ministry of Oceans and Fisheries(PES5230) and was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government (MSIT)(No.RS-2023-00218913).

Tuesday, August 27, 16:30-18:00 h,
Session: Sustainable Maritime Logistics

Keywords: AIS Data, Semi-Supervised Learning, Imputation

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Tuesday, August 27, 16:30-18:00 h,
Session: Sustainable Maritime Logistics

Spatial-Temporal Analysis of Ship Collision Risk

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Abstract. The ongoing increase in maritime traffic has caused an impact on the occurrence of safety accidents at sea. Consequently, finding out the causal relationship to these accidents has become an important field of research to ensure safe navigation. Since the scale and the cost of the damage caused by ship collisions are tremendous, research efforts are currently being actively conducted to avoid catastrophes by analyzing their characteristics, which are mostly influenced by human factors. This paper presents an approach that enables the investigation of ship collisions at sea in terms of both space and time. By utilizing the AIS data, a map is created that represents the relative traffic density, which indicates the relative proximity between ships. Then, using the maps created, a Convolutional Neural Network (CNN) model is trained for the classification of ship collision. The approach presented in this study aims to enhance maritime safety through the utilization of spatial-temporal analysis of collision occurrences. First, from the perspective of spatial analysis, Grad-CAM is utilized to investigate a specific region of the density map that has a significant impact on collision occurrences. Second, from a temporal perspective, the study also analyzes changes in marine traffic and the timing of collisions using transition analysis in relation to collision events. From the maps created from AIS data, we showed the difference between cases where ship accidents occurred and cases where accidents did not occur in influence from the perspectives of time and location using the maps proposed in this study.

1 Introduction

The surge in maritime freight volume post-COVID-19 has increased vessel operations, consequently leading to a rise in collision accidents at sea [1]. The major casualty incidents reported from 2014 to 2022 were collisions [2]. Collision is the type of accident reported as the third most common cause of accident in 2022 according to the Safety Shipping Review 2023 [3]. For this reason, continuous attention and research for safe navigation are needed based on the COLERGs [4] prescribed by IMO.

To prevent collision between ships, it is necessary to focus on the factors related to the collisions [5] and safety distance [6]. In particular, the safety distance between ships is utilized by developing a Collision Alert System (CAS) and a Decision Support System (DSS) based on the ship domain [7]. The ship domain can be generated based on AIS data, which is the past historical data of the ship. Among the types of ship domain, the empirical ship domain which is defined in consideration of the characteristics for operation at sea and marine weather conditions is used to predict the collision risk [8]. However, there are some limitations, because the relationship to the collision occurrence could not be identified. The contribution of this study is summarized in detail as follows.

- Generated maps serve as training data for a CNN model capable of classifying collision accidents. Additionally, we utilize Grad-CAM to identify significant regions within the images influencing collision occurrences.
- Through the generation of ship transit patterns for each maritime area at various time intervals, we analyzed shifts in ship traffic volume before and after collision accidents, identifying key traffic patterns.

2 Methodology

An overview of the proposed framework in this study is shown in Figure 1.

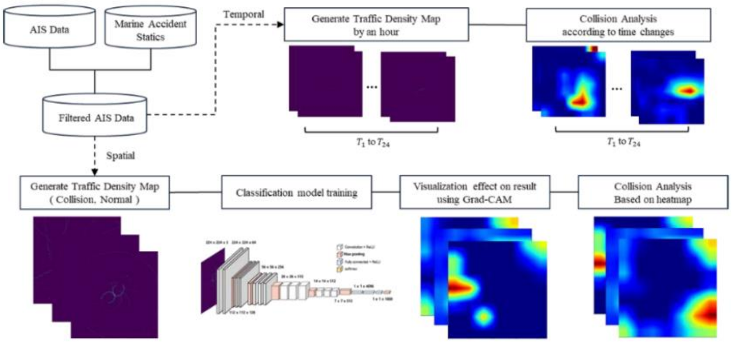


Fig.1: An overview of the proposed framework

To represent the relative trajectory based on the distance between ships, marine accident statistics and AIS data are used. The method of obtaining the distance between the base ship and the target ship followed the method of [9].
The relative density map is created based on the latitude and longitude of accidents, aligned according to a set distance. By analyzing this map and heatmap results, the variance trend is confirmed by calculating the degree of change when an accident occurs. The distance between the point where the value changes significantly (the point of maximum tangent line slope change) and the centroid is calculated. For temporal analysis, the traffic density map is divided hourly. During this process, the occurrence of accidents within each time zone is determined using collision timestamps and a pre-trained classification model.

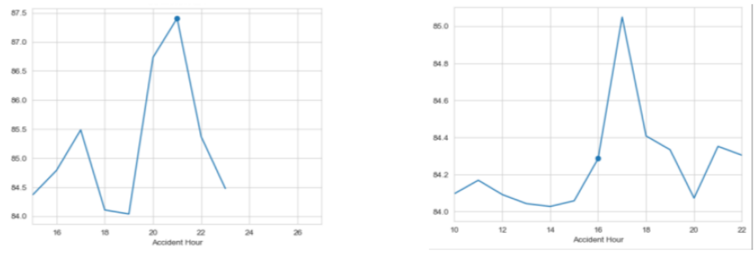
3 Results and Conclusions

Depending on the distance between ships, the performance of the model was different because the expressible marine traffic was different at the same latitude and longitude, and the performance of models with a 10km limitation from base ship to target ship as shown in Table 1.

Model	Performance			
	Precision	Recall	F1-score	Accuracy
ResNet	0.5	0.060606	0.108108	0.5
MobileNet	0.733333	0.333333	0.458333	0.606061
EfficientNet	0.72093	**0.939394**	**0.815789**	**0.787879**
ResNext	0.857143	0.181818	0.3	0.575758
VGG16	**1**	0.090909	0.166667	0.545455

Table 1: Classification performance of collision

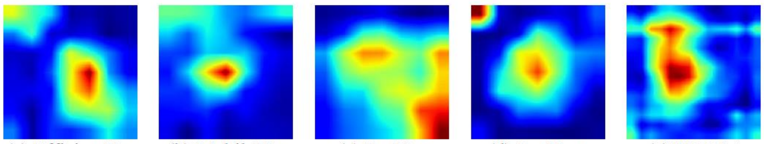
From a temporal point of view, when examining the pixel value changes in the generated maps, it was confirmed that the major accident cases exhibited specific patterns as shown in Figure 2.



(a) (b)

Fig.2: The changes in pixel values over time for collision cases. The blue dot represents the time of the accident, with the horizontal axis showing the time and the vertical axis representing pixel values

Based on this result, when Grad-CAM was applied, the result of deriving the inflection point for collision cases showed similarity as shown in Figure 3.



(a) EfficientNet (b) MobileNet (c) ResNet (d) ResNext (e) VGG16

Fig.3: Average heatmap for classification results depending on the model

In summary, there is a strong concentration around the centroid in case of collision. This framework introduces a method to check the regional impact of Grad-CAM results for collision classification. Further, we will apply the same framework for other marine accident cases such as fires, flooding, etc.

Acknowledgments. This research was supported by Korea Research Institute of Ships and Ocean engineering a grant from Endowment Project of “Development of Open Platform Technologies for Smart Maritime Safety and Industries” funded by Ministry of Oceans and Fisheries(PES5230) and was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT)(No.RS-2023-00218913).

Keywords: Empirical Ship Domain, Collision Risk Analysis, Grad-CAM, XAI

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Tuesday, August 27, 16:30-18:00 h,
Session: Sustainable Maritime Logistics

Long-Term Forecasting of Pollutant Emissions in the Arctic Ocean Based on Cross-Dimensional Dependency Network using Arctic Ship Traffic Data

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Abstract. Recently, due to global warming, the ice in the arctic ocean is rapidly melting, leading to an increase in the navigable period for ships in the Arctic Ocean. As a result, the number of ships passing through the Arctic Ocean is also steadily increasing, leading to a rise in the emission of pollutants. These environmental changes are exacerbating pollution. We aim to analyze the changes in pollutant emissions in the Arctic Ocean using Arctic Ship Traffic Data (ASTD). Additionally, we aim to conduct long-term predictions of pollutant emissions from ships passing through the Arctic Ocean to forecast the future pollution levels. To achieve this, we propose a neural network architecture called Cross-Dimensional Dependency Network. This model has been proposed to improve the accuracy of long-term predictions of pollutant emissions in this region. Compared to existing spatio-temporal data-based long-term prediction models, this model shows an improvement in prediction performance of over 10%. This model is expected to be used as fundamental data for the development of environmental protection policies by predicting future pollution levels in the Arctic Ocean and comparing them with current IMO regulations and policies.

1 Introduction

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Climate change is causing a reduction in ice along the Arctic Ocean routes, impacting navigation in this particular region [1]. In the past, ships could navigate for five months, especially during the summer. However, in 2020, it was reported that ships could navigate for seven months, and this period is expected to increase gradually [2]. Indeed, over the past decade, maritime activity in the Arctic Ocean region has increased by an average of 7% per year, with winter navigation activity also significantly increasing [3]. These changes are also accelerating the increase in pollutants emitted from Arctic shipping routes.

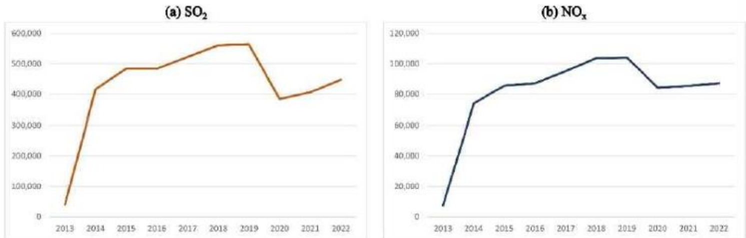

Fig.1: The trend of changes in the amounts of SO2 and NOx emitted along the Arctic route from 2013 to 2022.

Fig. 1 visualizes the emission data included in the Arctic Ship Traffic Data (ASTD). According to this result - although emissions decreased from 2019 to 2020 due to factors such as COVID-19 and the Ukraine conflict leading to a reduction in vessel traffic - there is a consistent upward trend in emissions over the past decade [4]. We utilize the ASTD to perform long-term predictions of pollutants discharged through the Arctic maritime routes. Additionally, we propose a novel artificial neural network architecture called Cross-Dimensional Dependency Networks (CDDNet) to enhance the accuracy of long-term predictions of pollutants discharged through the Arctic maritime routes. We expected that the proposed CDDNet will contribute to establishing relevant policy regulations by providing accurate long-term predictions of emissions discharged along the Arctic shipping routes.

2 Cross-Dimensional Dependency Network

We aim for a long-term forecasting of the emissions of 7 substances (CO, CO_2, SO_2, NO_x, N_2O, NMVOC, CH_4) at ASTD. Fig. 1 shows the overall architecture of the Cross- Dimensional Dependency Networks (CDDNet) used to predict seven emissions from ships navigating in the Arctic Ocean. CDDNet is composed of n Cross-Dimensional Dependency mapping blocks. Each block consists of an embedding layer composed of linear layers, followed by a temporal layer and a spatial layer arranged in sequence. This structure is designed to learn temporal and spatial features in the input data. To generate input data for each network, the collected location information of the ships and at the same time the individually discharged emissions at each location are represented on a 32x32 grid. Subsequently, input data of size (32, 32, *i*) is generated by considering sequence information of *i* instances to be trained. Before entering the CDDNet, the input data is partitioned into patches using patch embeddings, with the entire grid divided into patch units.

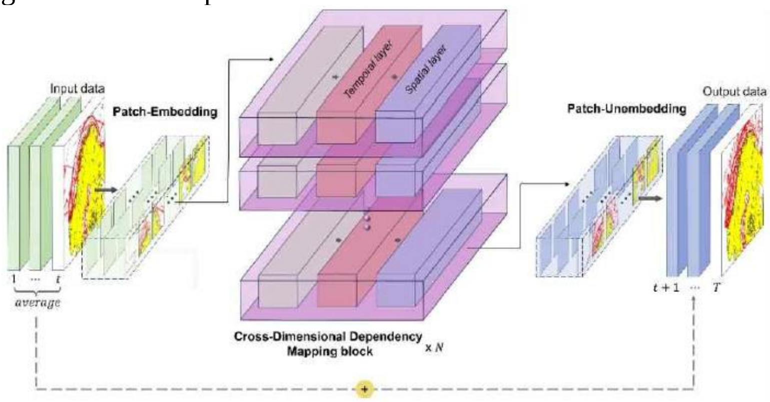

Fig.2: Architecture of Cross-Dimensional Dependency Networks.

This input data is utilized to train the temporal and spatial features of patch units via the CDDNet. The acquired temporal and spatial features will enable the prediction of emission quantities at the anticipated time points through patch unembeddings. Ultimately, generating a grid set with dimensions of (32,32, *T*), where *T* represents the time points for long-term forecasting.

3 Experiments

We have conducted comparative experiments between CDDNet and two representative baseline models (ConvLSTM [5], SimVP [6]) commonly used in spatio-temporal prediction to evaluate the predictive performance. The experimental data have been collected from ASTD over a period of 10 years from January 2013 to December 2022. The training and test data have been divided into a 7:3 ratio. The forecasting term has been set at one month and six months ahead for experimentation. For performance evaluation, we utilized metrics including Mean Squared Error (MSE), Mean Absolute Error (MAE), Peak Signal-to-Noise Ratio (PSNR), Structural Similarity Index (SSIM) MSE and MAE, which are metrics for evaluating the difference between actual values and predicted values. Smaller values indicate a better performance of the prediction model. PSNR and SSIM are metrics for evaluating the similarity between grids containing actual emissions, represented as (32, 32, *i*), and grids containing predicted emissions, also represented as (32, 32, *i*). Larger values indicate a better performance of the forecasting model.

Table 1 represents the results of the comparative experiments. Initially, on a one-month prediction basis, our proposed model exhibited improved performance across all metrics compared to the existing model. While there were variations across performance metrics, they showed enhancements ranging from 3% to 10%. Furthermore, on a six-month prediction basis, there were performance improvements in all metrics except for the minimum PSNR, with up to a 26% enhancement in prediction performance. These results demonstrate that the structure of our proposed CDDNet is suitable for long-term prediction of pollutants emitted from ships in the arctic route.

Forecasting Term	Metric	ConvLSTM	SimVP	CCDNet (Our)
One Month (30 days)	MSE	5.074	4.921	**4.401**
	MAE	2.370	2.587	**2.154**
	PSNR	44.203	44.267	**44.613**
	SSIM	0.919	0.917	**0.928**
Half of Year (180days)	MSE	5.931	5.881	**5.757**
	MAE	2.550	3.204	**2.534**
	PSNR	43.651	**43.769**	43.678
	SSIM	0.911	0.897	**0.912**

Table 1: comparative experiments between CDDNet, ConvLSTM [5], and SimVP

4 Conclusion

Our study presents a new CDDNet artificial neural network architecture for long-term prediction of substances discharged from ships in the Arctic Ocean. We found that the proposed model outperformed existing models, showing up to a 26%-improvement in performance, particularly in long-term predictions, such as 6 months ahead. By utilizing such predictive models, precise estimations of emissions from ships within the Arctic route can be made, serving as crucial foundational data for environmental regulations. Future research aims to further enhance the existing model structure to develop a model capable of accurate predictions up to 5 years ahead.

Acknowledgments. This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (MSIT)(No.RS-2023-00218913) and by MSIT, Korea, under the Grand Information Technology Research Center support program (IITP-202-2020-0-01791) supervised by the Institute for Information & Communications Technology Planning & Evaluation.

Keywords: Cross-Dimensional Dependency Network, Arctic Ship Traffic Data, Arctic Ocean Pollutant Emission, Long-Term Forecasting

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Waterway Transportation

Tuesday, 27.08.2024, 16:30-18:00, Room 122

Chair: Frank Meisel

A Graph Neural Network Approach for the Waterway Ship Scheduling Problem:
Peter Wenzel, Nahom Tsehaie, Raka Jovanovic, Frederik Schulte

Multi-Period Containerized Battery Swapping Station Location Planning for Inland Waterway Transportation:
Virgilio Ma Jr Ramos, Bilge Atasoy

A Stochastic Optimization Model for Tramp Scheduling with Many-to-many Matching and Speed Optimization:
Liangqi Cheng, Xi Lin, Xiwen Bai

Tuesday, August 27, 16:30-18:00 h,
Session: Waterway Transportation

A Graph Neural Network Approach for the Waterway Ship Scheduling Problem

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Abstract. Planning the allocation of berths for vessels in narrow waterways requires considering various constraints such as waterway capacity, vessel specifications, and timing requirements for ship movements. The Waterway Ship Scheduling Problem (WSSP) was introduced to optimize ship movements and berth allocations in waterway systems. It can be formulated as a Resource Constraint Project Scheduling Problem (RCPSP). This work employs Graph Neural Networks (GNN) to predict solutions for RCPSP, improving schedule quality and efficiency. The GNN results are compared in terms of the quality and the computational time of the solution. They highlight the GNN model's capability in managing complex constraints and precedence relations, outperforming OR tools by 96.3% in average relative time performance, especially in more intricate scenarios. These findings advocate for the practical application of the GNN model in short-term port planning, particularly in cases of short-noticed replanning due to operational failures.

Keywords: Inland Waterway Transportation, Graph Neural Networks, Optimization

Tuesday, August 27, 16:30-18:00 h,
Session: Waterway Transportation

Multi-Period Containerized Battery Swapping Station Location Planning for Inland Waterway Transportation

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Abstract. The pursuit of sustainable solutions has pushed for the development of innovative logistics decisions for alternative energy systems. One such example is the containerized battery swapping station designed for inland water transportation. Ensuring the successful adoption and implementation of this new energy system requires the availability of adequate infrastructure to power the whole network. Given the restricted initial budget for implementation, it is important to select the locations of these stations wisely. This study introduces a multi-period model that optimizes battery swapping station locations to maximize the flow covered across an entire network. By incorporating the multi-period decision, we capture the dynamic evolution of the network, which includes the adoption of battery swapping across different years, and the potential expansion of the energy infrastructure in response to the demand. We present a case study using a network based on the inland waterways of the Netherlands and using flow data derived from inland vessel trips. A sensitivity analysis is conducted to underscore the importance of considering vessel range and station capacity in achieving a comprehensive network coverage.

Keywords: Facility Location, Inland Waterway Transportation, Battery Swapping, Flow refueling, Strategic Level Optimization

Tuesday, August 27, 16:30-18:00 h,
Session: Waterway Transportation

A Stochastic Optimization Model for Tramp Scheduling with Many-to-many Matching and Speed Optimization

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Abstract. The tramp shipping industry involves large volumes of homogeneous cargoes transported around the world. Tramp companies route vessels to pick up and deliver these cargoes in order to minimize total costs, but the scheduling process becomes increasingly challenging due to the uncertainties and risks in the tramp market. In addition, long transportation time and dispersed pickup-and-delivery regions cause delayed responses to market volatilities and exacerbate the complexity of short-term decision-making. This study introduces a tramp scheduling model considering stochastic future revenues to enhance short-term decisions. The model employs "many-to-many" matching in the tramp market, where each vessel can transport multiple cargoes simultaneously, and a single cargo can be split and delivered by multiple vessels. Initially, a two-stage stochastic arc flow formulation is presented within a space-time network, enabling vessel speed optimization during arc selection. Subsequently, Dantzig-Wolfe Decomposition is utilized to manage the extensive set of variables, resulting in a path flow master problem and pricing subproblems, each solved for a specific vessel and scenario. A column generation solution method is devised, incorporating a label-setting algorithm for the subproblem in each iteration that can determine the cargo quantity decisions brought by split deliveries. This label-setting algorithm is developed through an in-depth analysis of the extreme structure of delivery quantities on a specific route. Numerical experiments are conducted to demonstrate the efficiency of the proposed algorithms.

Tuesday, August 27, 16:30-18:00 h,
Session: Waterway Transportation

Keywords: Tramp Shipping and Routing, Vessel Scheduling, Column Generation, Stochastic Programming

Keynote

Wednesday, 28.08.2024, 9:00-10:00, Room 221

Chair: Leonard Heilig

Keynote by Dr. Yvo Saanen (Portwise)

Dr. Yvo A. Saanen is Managing Director and Founder (1996) of Portwise (formerly called TBA), a leading terminal design and simulation company in the Netherlands. He is in charge of all port & terminal related projects all over the world in their planning and optimization process of container terminals by means of simulation and emulation.

In this role, he has participated in various projects, ranging from long term development, process improvement, terminal extensions and redesign of handling systems to design of greenfield terminals. Examples are the DPWorld's facility in Antwerp, and HPH's Euromax facility in Rotterdam, and OOCL's facility in Long Beach, but also recent automated terminals in Rotterdam by APMT and DP World.

Dr. Saanen holds an MSc in Systems Engineering and a PhD on the design and simulation of robotized container terminals, both from Delft University of Technology. He is a lecturer at the Center of Maritime Economics Logistics (Erasmus University Rotterdam), teaching simulation and logistics and, in various bodies, lectures about terminal design by means of simulation, and publishes regularly about his work in scientific magazines as well as business magazines.

Tuesday, August 28, 9:00-10:00 h,
Session: Keynote

Digitization to Enable Sustainable Supply Chains

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Abstract. The need for developing sustainable supply chains has never been more critical, driven by the global demand for environmental responsibility and efficiency. Leveraging the full capabilities of digitization is paramount to achieving this goal. Key prerequisites for digitization in the supply chain include data integration, real-time visibility, interoperability, advanced analytics, cybersecurity, IoT deployment, AI and machine learning adoption, blockchain technology, cloud computing, and sustainable practices. The underlying technologies that enable a digitized supply chain are primarily IoT, AI, machine learning, blockchain, and cloud computing.

IoT facilitates real-time tracking and monitoring of goods, enhancing visibility and decision-making. AI and machine learning provide predictive analytics and optimization for supply chain processes, reducing waste and improving efficiency. Blockchain ensures secure, transparent, and tamper-proof transactions, promoting trust among stakeholders. Cloud computing offers scalable storage and processing power, allowing seamless data integration across various supply chain functions.

These technologies have been successfully applied in industries like automotive (e.g., BMW's use of blockchain for part tracking), retail (e.g., Walmart's implementation of IoT for inventory management), and logistics (e.g., DHL's adoption of AI for route optimization), demonstrating significant improvements in sustainability and efficiency.

Where are we in the terminal industry? In many of these areas, we see steps in the right direction, but by no means full adoption. Although we are collecting heaps of data, we seem not to be able to get solid analytics out of them. We still struggle with poor data

quality whether it's EDI or equipment and maintenance data. We still allow trucks to come to the terminals without appointments, clogging up the gate during the rush hours. Yard and vessel planning relies mostly on people, without proper tools to learn from the past and plan for the near future. In terms of maintaining cyber security throughout facilities we lack visibility on what's in the machines themselves. Finally in terms of terminals planning, we are often steering in the dark, developing facilities like patchwork, without solid long-term plans.
In the talk today, I'll discuss the prerequisites for terminals of the future, in terms of digitization as well as creating a sustainable operation, embracing the latest technologies, available and proven.

Keywords: Digitization, Internet of Things, Artificial Intelligence, Machine Learning,Cyber Security

Green Innovations in Smart Port Logistics: Future Directions

Wednesday, 28.08.2024, 10:30-12:00, Room 121

Chair: Eon-Kyung Lee

A Hybrid Testing Approach to Secure the Smooth Go-Live of Automated Container Terminals:
Holger Schütt

AI-Enhanced Smart Maritime Logistics: Data-Driven Innovations at South Korean Ports:
Hyerim Bae

New Fuels and their Emissions in Maritime – Considerations for Sustainable Port Logistics:
Kang-Ki Lee

Innovative OSS Terminal Concept for Efficient Handling of Mega Container Ships:
Eon-Kyung Lee, JungJoon Bae

A Hybrid Testing Approach to Secure the Smooth Go-Live of Automated Container Terminals

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Abstract. As a response to increasing requirements from the shipping lines, terminal operators are forced to look at the automation of processes and equipment to stay competitive in the market. Greenfield terminals are often directly planned to run automated, but also Brownfield (i.e. existing) terminals have to be converted. Especially automated terminals require control systems with high complexity, as in the case of exceptions and change of schedules human interaction has to be minimised. To secure a smart operation of the terminal already the layout planning must be aligned to the assumed type of business (vessel and package sizes, transhipment rates, dwell times and much more).
During the installation of the Terminal Operating (TOS) and Fleet Management Systems (FMS), emulation-based test systems allow functional and productivity tests using Virtual Terminals. This state-of-the-art approach of testing may start long before the real equipment is delivered and configured.
In this paper, the author will present the next generation of emulation-based testing, the Hybrid Testing approach connects the emulation-based approach with real equipment. It will be based on a case study made in South Korea. Instead of using the test environment for the IT systems only, also the acceptance testing of the AGV has been included to the test environment.

The Dongwon Global Terminal (DGT) is located in Busan New Port in South Korea. It is a Greenfield terminal and will be fully automated:

- remotely operated Double Trolley Quay Cranes (QC) delivered by Hyundai who discharge and load the vessels

- automated stacking cranes (ASC), some of them with an additional cantilever functionality, also delivered by Hyundai
- automated guided vehicles for transporting the containers between the QC and the ASC. The equipment as well as the FMS were developed by the Korean Hyundai Rotem in cooperation with VDL from the Netherlands.
- the TOS OPUS was delivered by Cyberlogitec/Korea.

Busan Port Authority provided the infrastructure including the QCs as well as the ASCs to the terminal operator DGT. Nevertheless, the AGVs including the FMS as well as the TOS OPUS were ordered by DGT themselves. Hyundai Rotem delivered the AGVs as well as the FMS for the AGVs. It was the first FMS implementation for Container Terminals by Hyundai Rotem.

This configuration leads to the situation that DGT has to perform the integration testing of the components on their own responsibility fort he first time. For performing the testing, DGT has built a Hybrid Testing environment - based on the CHESSCON Virtual Terminal product, an emulation-based testing tool for container terminals.
Within the Hybrid-Testing-Solution

- Piscesoft as a software integrator connects the FMS as well as OPUS (Cyberlogitec's TOS) to CHESSCON

Within the hybrid testing solution:

- DGT together with Piscesoft set up the scenario for the Tests within CHESSCON

DGT and Piscesoft use

- OPUS to organize the terminal operation
- QC emulators to discharge and load virtual containers from/to vessels
- the ASC emulators to stack containers in the yard blocks / deliver them from the yard blocks
- the real FMS from Hyundai Rotem together with the real AGVs to transport the (virtual) containers at the waterside

The Hybrid Testing itself is carried out by DGT supported by Piscesoft, whilst the CHESSCON team support them from the back-office.

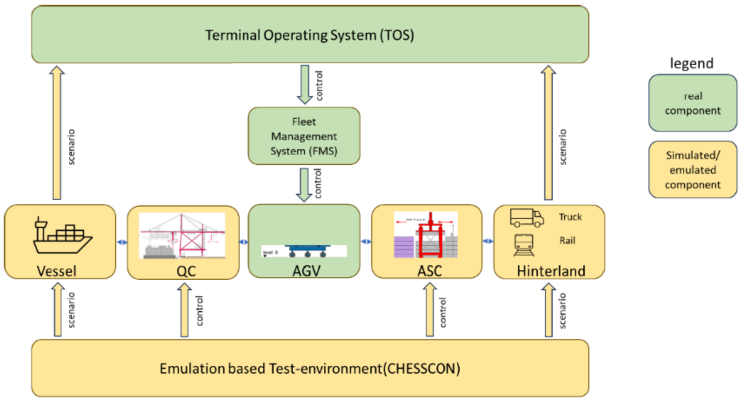

Fig. 1: Hybrid Testing Approach of Dongwon Global Terminal/South Korea

On April 5th the terminal was inaugurated successfully by serving the first vessel very successfully.

A further outlook on what can be done is the following: During the whole live operation the developed test systems may be used to secure the installation of new software releases of the TOS and FMS. Thus, new strategies may be tested to guarantee an optimal and stable operation before going live at the terminal. Additionally, the virtual test environment may be connected to the live operation of the terminal to synchronise the state of all terminal components with their simulated counterparts in the model. In this way, the terminal model will become a Digital Shadow. By providing simulation-based operation support methods in the model, a bidirectional interaction between the model and real-world opertation may be achieved. Thus, a Digital Twin of the terminal will be in operation.

Keywords: Container Terminal, Emulation, Hybrid testing, Digital Twin, Integration Test, CHESSCON, Piscesoft

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Tuesday, August 28, 10:30-12:00 h,
Session: Green Innovations in Smart Port Logistics: Future Directions

AI-Enhanced Smart Maritime Logistics: Data-Driven Innovations at South Korean Ports

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Abstract. In maritime logistics, centered around ports, data-driven methodologies utilizing artificial intelligence and big data are emerging as significant approaches. Ports, situated at the nexus of sea and inland logistics, are increasing in importance. The optimization of shipping-port connectivity and port-inland linkages is an indispensable element. Precisely predicting the estimated time of arrival of ships and integrating this information with port operations is crucial. For this, real-time collection, analysis, and utilization of information about maritime and port conditions are necessary. Inland logistics is also closely tied to port logistics optimization, particularly in relation to the arrival and departure of trucks on land, necessitating integrated operations. Recently, the need for solutions considering safety and environmental factors in optimizing maritime logistics has also gained prominence. This paper introduces data-driven approaches to smart maritime port logistics, focusing on case studies from South Korea.

Keywords: Smart Maritime Logistics, AI, Port Connectivity

Tuesday, August 28, 10:30-12:00 h,
Session: Green Innovations in Smart Port Logistics: Future Directions

New Fuels and their Emissions in Maritime – Considerations for Sustainable Port Logistics

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Abstract. In 2022, the maritime industry emitted approximately 858 million tonnes of CO_2 (OECD, 2024). The IMO aims to achieve net-zero greenhouse gas emissions by 2050 (IMO, 2023), requiring the adoption of carbon-neutral fuels such as hydrogen, ammonia, and methanol. These fuels, being cryogenic or toxic, will significantly affect port operations. Sustainable port logistics face challenges from new fuels and emission control technologies, including the management of hazardous by-products. For example, scrubbers that reduce sulfur oxides (SO_x) produce toxic wastewater treated with sodium hydroxide, posing environmental risks. Ports will need to handle the unloading and storage of captured sulfur and carbon carefully. Managing large volumes of extracted materials from fuel and emissions necessitates the development of policies for safe and sustainable operations. This includes creating logistics systems for hazardous materials and adapting infrastructure to accommodate new fuels. Ensuring sustainable port operations is crucial for meeting global emissions targets.

Keywords: Port Emissions, Maritime Industry, Sustainable Port Logistics

Tuesday, August 28, 10:30-12:00 h,
Session: Green Innovations in Smart Port Logistics: Future Directions

Innovative OSS Terminal Concept for Efficient Handling of Mega Container Ships

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Abstract. This study introduces the Overhead Shuttle System (OSS), a novel terminal concept designed to handle ships of 25,000 TEU and above, ensuring efficient mass loading and unloading within 24 hours. The OSS enhances the functionality of vertical container terminals by employing a dual Automated Stacking System (ASC) to manage 10 rows of containers. To address productivity declines in container yards during peak ship and truck operations, the OSS integrates overhead shuttles in pairs per row, significantly improving yard performance.
The OSS features a unique infrastructure where containers unloaded from ships via Quay Cranes (QC) are swiftly transported to the yard by the overhead shuttles when aligned. When misaligned, flatcars on the ground horizontally transfer containers to the overhead shuttles for yard storage. A partial-scale OSS prototype was developed and tested at a port terminal, while a full-scale model was developed and operated using a digital twin. The results demonstrated a QC productivity rate of over 39 moves per hour, proving the OSS's capability to process mega container ships within 24 hours. This innovative concept, validated from design to field demonstration, marks a significant advancement in terminal operations.

Keywords: Overhead Shuttle System, Vertical Container Terminals, Digital Twin

Vessel Planning

Wednesday, 28.08.2024, 10:30-12:00, Room 122

Chair: Dario Pacino

The Economic Value and Environmental Benefits of Accurately Predicting Arrival Times in International Shipping:
Thalis Zis

Stowage Planning with Hybrid Slots, Hazardous Cargo and Stability Limits:
Magnus Levinsen, Oliver Thomsen, Dario Pacino, Line Reinhardt

Attribute Dynamics and Machine Learning in Berth Time Prediction: Developing a Selection Framework for Algorithms Based on Time-Variant Data Availability and Vessel Characteristics:
Pierre Bouchard, Stefan Voß, Leonard Heilig

Predicting Ferry Delays Using Machine Learning and Open Data:
Malek Sarhani, Mohamed El Amrani

Tuesday, August 28, 10:30-12:00 h,
Session: Vessel Planning

The Economic Value and Environmental Benefits of Accurately Predicting Arrival Times in International Shipping

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Abstract. In recent years, the decarbonization of international shipping has been monopolizing the priorities of researchers and policy makers. Reducing shipping emissions is now required by the International Maritime Organization, while other regional regulations are also moving towards a polluter-pays-principle. Shipping can reduce its emissions through a combination of technological, operational, and market-based maesures (MBM). More often than not, the majority of emissions reduction strategies is focusing on speed optimization problems at either the individual or fleet level. While the literature has been exhaustive in this subject, with the new capabilities offered from the explosion of data, there may still be some low-hanging fruits in this quest. Additionally, the role of ports is now seeing increasing attention as an enabler to further cut the shipping sector's emissions. Ports have started designing novel strategies to improve local air quality, as well as to promote green practices. Coupled with new technologies and methodologies, more data as well as a wider access to AIS information, there are new ways for ports and ship operators to improve the efficiency of their operations, and utilize concepts such as the Virtual Arrival. In this work, we use port call data for eight different ports on the actual time of arrival of ships, and contrast it with the predicted time of arrival as reported by the ship masters. We estimate the potential cost and environmental savings from utilizing such data, and we make recommendations on how to improve the quality and usability of such data, as well as their truthfulness. The paper concludes with a discussion of policy implications from the Revised IMO Strategy, potential

MBMs, and the future research questions pertaining the adoption of alternative fuels.

Keywords: Green Ports, Arrival Times, Port Operators, Sustainable Shipping, Maritime Logistics

Tuesday, August 28, 10:30-12:00 h,
Session: Vessel Planning

Stowage Planning with Hybrid Slots, Hazardous Cargo and Stability Limits

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1 Introduction

Short-sea shipping is strategically important for the EU to reach a 60%-reduction of transport emissions by 2050 [1]. Roll-On Roll-Off (RORO) shipping plays a major role in achieving this goal as the ability to transport wheeled cargo can help increase the modal shift from road to sea. New ship designs and alternative fuels will likely achieve the major breakthrough; their implementation is further in the future. Meanwhile, digitalization efforts can help reduce emissions through better asset utilization, minimization of fuel consumption, and optimization of handling operations. Recently, RORO stowage planning, the assignment of cargo-to-vessel positions, has gained the attention of the academic community and the industry [2, 5–8]. The first article on the RORO Shiping Stowage Planning (RSSP) used a lane representation of the problem that maximizes revenue
and ensures the stability of the ship [8]. Small instances can be solved using a mixed-integer program (MIP) formulation, and practical-sized problems; results can be achieved by using heuristics. An alternative strategy that better represents the vessel involves employing a grid layout that enables flexible placement of the cargo [3]. The mathematical formulation places cargo considering grouping limitations and aims to reduce repositioning. The formulation cannot be solved for practical-sized problems with a MIP solver. Hence, an Adaptive Large Neighborhood heuristic is used to solve it [2]. In an extension [6], the impact between cargo revenues and fuel consumption is studied under

variable cargo arrival times. A more practical approach uses predefined cargo positions (slots) [5].

A MIP formulation that minimizes the use of ballast water (and, in turn, fuel consumption) is shown to provide optimal results quickly. A step-wise heuristic was, however, needed to solve the incorporation of dangerous cargo [4]. The slot formulation was extended to include the handling of heterogeneous cargo. The formulation in [7], however, disregarded ballast water minimization. Presenting a novel MIP formulation for the RSSP, we aim at combining and improving current methods to allow the optimization of ballast water while ensuring vessel seaworthiness, correctly handling dangerous cargo and planning for multiple cargo types.

2 Problem formulation

Our MIP formulation builds upon the hybrid-slot representation introduced by Puisa et al. [7]. For each cargo type, a grid of possible cargo positions (slots) is pre-computed and constraints to avoid overlapping cargoes are posted. The objective of the formulation is the minimization of a weighted linear sum between the use of ballast water and the amount of not-loaded cargo. The main decision variable is binary and represents the assignment of a specific piece of cargo to a slot in the vessel. Continuous variables are used to decide on the amount of ballast water used to stabilize the vessel.

The model takes into account not only different cargo sizes but also handles special freight, such as refrigerated and hazardous cargo. The latter ensures that IMO segregation rules are satisfied. Segregation rules are modeled with a constraint between all pairs of cargo and all pairs of positions. This results in a large number of constraints, which we handle by implementing lazy evaluation, which drastically improved the computation times. Vessels leaving a port must be seaworthy, and hence have to adhere to a number of restrictions, which govern how weight can be distributed on a vessel.

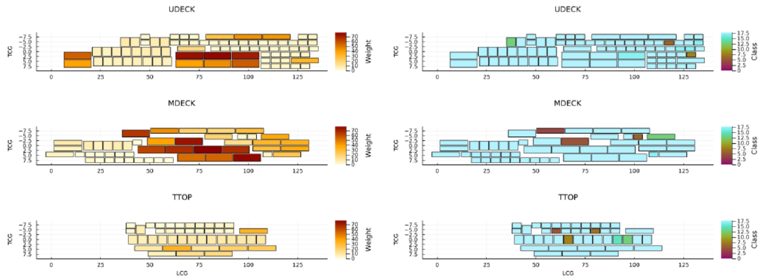
As it is not always possible to achieve feasible conditions by the arrangement of cargo, ballast tanks can be strategically filled with water. Since we model ballast water and variable cargo loads, many stability constraints need to be linearized. This requires the use of interpolations and linear regression. Our model can handle center-of-gravity limits and stress force limits (shear and bending). Our linearizations produce seaworthy stowage plans, which have been validated using our industrial collaborator's loading computer.

3 Preliminary Results

The model is tested on three different ship sizes and five instances with different levels of hazardous cargo. Each instance was solved using Gurobi 11.0.1 and on a Xeon Gold 6226R with eight available threads and a time limit of an hour. Preliminary results are shown in Table 1. For all ship sizes, instances 1-3 can be solved either optimally or within a 4%-MIP Gap. The formulation has a harder time finding good solutions for instances 4-5. Initial tests indicated that the performance drops when the amount of hazardous cargo is more than 6% of the booking list. This indicates that further analysis needs to take place and further investigation might be needed to improve the formulation. Figure 1 shows a stowage plan solution, depicting the weight distribution (a), and the arrangement of hazardous cargo (b). As expected, heavy cargo is centered at the longitudinal axis but is spread vertically. The hazardous cargo is spread across the whole vessel.

Ship	Instance	Time (s)	Ballast Water (t)	Gap%	Area Util.%	Haz. Prop.%
Small	1	14	0.00	0.0	88.5	0.0
Small	2	201	0.00	0.0	88.5	1.7
Small	3	410	1.24	0.0	88.5	5.2
Small	4	3600	2.48	0.6	88.1	7.0
Small	5	3600	7.16	1.2	87.4	9.9
Medium	1	657	0.00	0.0	88.8	0.0
Medium	2	3600	0.00	4.5	80.0	2.6
Medium	3	3600	203.13	4.2	81.6	5.7
Medium	4	3600	0.00	46.2	44.5	8.8
Medium	5	3600	462.46	28.6	59.6	12.7
Large	1	635	0.00	0.0	95.9	0.0
Large	2	3600	365.38	4.4	87.9	2.8
Large	3	3600	818.56	1.9	94.6	5.8
Large	4	3600	0.00	30.4	60.6	7.8
Large	5	3600	0.00	15.1	70.3	10.0

Table 1. Preliminary results for three different ship sizes and five instances with varying levels of hazardous cargo



(a) Cargo placed by weight (b) Cargo placed by hazardous class

Fig. 1. A solution for the small ship for instance 3. The figure on the left shows the cargo placed by weight, and the figure on the right shows the cargo by hazardous class.

4 Conclusion

We developed a MIP formulation of the RSSP that improves upon current methods. Our model accommodates variable cargo types, handles the ship's stability, and plans for refrigerated and hazardous cargo. The use of lazy evaluation for hazardous cargo constraints improve the computational times of the formulation. Preliminary results are promising, but further research is needed to reliably handle hazardous cargo, and to stress-test the formulation.

Keywords: Stowage Planning, RORO Shipping, Ballast Water, Mixed-Integer Linear Programming, Maritime Optimization

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Tuesday, August 28, 10:30-12:00 h,
Session: Vessel Planning

Attribute Dynamics and Machine Learning in Berth Time Prediction: Developing a Selection Framework for Algorithms Based on Time-Variant Data Availability and Vessel Characteristics

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Abstract. The effective allocation of limited quay space in ports, known as the berth allocation problem (BAP), relies on accurate predictions of vessel turnaround time (VTT). This paper presents a framework for selecting machine learning models based on the specific temporal characteristics, availability, and quality of available data. Using a real dataset from the port of Hamburg with dynamic variables from terminal operators and static vessel information, the framework addresses inconsistencies in data availability and quality from various stakeholders. Our analysis highlights the need for different prediction models for various time intervals and vessel types, specifically feeder vessels and Ocean carriers. The proposed framework integrates these models to optimize VTT predictions, enhancing port planning and operational efficiency. Its flexibility and continuous improvement capabilities ensure robust and actionable insights, crucial for port logistics. Our findings show that using advanced machine learning techniques and adapting to the unique data dynamics of each vessel type significantly improves berth time predictions, supporting more efficient berth allocation and resource management.

Keywords: Vessel Turnaround Time, Berth Time, Machine Learning, Port Logistics

Tuesday, August 28, 10:30-12:00 h,
Session: Vessel Planning

Predicting Ferry Delays Using Machine Learning and Open Data

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Abstract. Public transportation, particularly ferry services, faces unique challenges in delay prediction due to variable maritime conditions, yet accurate predictions are vital for efficient transit system integration. Leveraging machine learning (ML) and open data, this study focuses on improving ferry delay predictions using data from Sydney, Australia, complemented by a case study from New York City. Various ML algorithms, including support vector regression (SVR) and gradient boosting (GB), were evaluated, with a particular emphasis on integrating internal data sources, such as GTFS static and real-time data with external weather data. The pre-processing of this data was critical, addressing missing values and outliers to ensure robust model training.

The study found that SVR and GB models significantly outperformed other algorithms in predicting ferry delays. SVR was particularly effective for long-term predictions, while GB excelled in real-time applications. Key predictive features included stop ID, route ID, and weather conditions, the latter having a notable impact on prediction accuracy. These results align with previous research that underscores the importance of operational and environmental factors in transit delay predictions. Explainable AI (XAI) techniques, such as Shapley values, were employed to assess feature importance, providing valuable insights into the factors most influencing on ferry delays. XAI revealed that operational features like stop ID and route ID were crucial determinants, echoing findings from existing literature. The integration of internal and external data sources proved essential in enhancing the accuracy of delay predictions,

highlighting the value of a comprehensive data approach in transit systems.

This research underscores the potential of ML and open data in addressing the complexities of ferry delay prediction. By accurately predicting delays, transit authorities can optimize schedules, improve passenger satisfaction, and ensure a better integration with other modes of public transportation. Future research could expand on these findings by applying similar methodologies to different transit systems and incorporating additional data sources, such as real-time passenger counts and maritime traffic data, further refining prediction models and enhancing their applicability.

In conclusion, the use of ML and open data offers a promising avenue for improving ferry delay predictions. The successful application of SVR and GB models in this study demonstrates their capability in handling the intricacies of maritime transit systems. Moreover, the application of XAI techniques provides a deeper understanding of the key factors affecting delays, facilitating the development of more effective and responsive transit schedules. This approach not only benefits ferry services but also offers insights that could be applied to other modes of public transportation, contributing to the overall efficiency and reliability of urban transit networks.

Keywords: Machine Learning, Ferry Services, Public Transport

Resilient Operations

Wednesday, 28.08.2024, 13:00-14:30, Room 121

Chair:Philip Cammin

Envision: An AI-Driven Wireless Sensing Technology for Cargo Ship Fire Detection:
Junye Li, Aryan Sharma, Yirui Deng, Deepak Mishra, Hiran Wijetilaka, Aruna Seneviratne

Optimizing Maintenance Scheduling Considering Predictive Maintenance Inaccuracy:
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Improving Safety of Navigation and Sustainability of Shipping through Innovative Autonomous Shipping Technologies in Asia Pacific: Case Study of Thailand:
Chackrit Duangphastra

Tuesday, August 28, 13:00-14:30 h,
Session: Resilient Operations

Envision: An AI-Driven Wireless Sensing Technology for Cargo Ship Fire Detection

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Abstract. The booming global container shipping industry highlights the challenges of onboard fire accident detection and prevention, especially in container holds. Existing smoke and temperature sensors respond slowly and are unable to pinpoint the location of the fire. To this end, we propose Envision, a wireless sensing-based fire detection system employing smart AI algorithms to predict cargo hold temperature, detect and locate fire using the WiFi Channel State Information (CSI). We empirically verified Envision through both a simulated cargo hold environment, as well as deployments on actual cargo ships with the help of industry partners. Consequently, the system demonstrates potential for early fire detection and localisation capabilities in cargo hold environments.

1 Background

Based on OECD forecasts, it is anticipated that by 2030, global transit will see one billion TEUs (Twenty-foot Equivalent Units). Current production levels reveal an annual output surpassing 400 million lithium-ion batteries and 15 billion aerosols, signalling a potential escalation in container fire hazards on cargo ships. For instance, the current fleet's largest vessels, accommodating 22,000 TEU, face a significantly heightened risk compared to smaller counterparts. The likelihood of a problematic container being on board is over four times greater on these larger vessels. Efficiently addressing on-board fires presents key challenges, notably preventing ignition and achieving early, precise fire detection, particularly below deck. Traditional cargo hold fire detection methods rely on simple smoke detection, offering delayed fire indication without pinpointing the exact container location. While there are five established core technologies available, each offering unique advantages, none adequately meets the critical requirements of fire localisation, low installation complexity, and cost-effectiveness. Therefore, an effective fire prediction and detection system must meet seven essential criteria:

- high detection sensitivity,
- rapid detection,
- hazard localisation capability,
- affordability,
- ease of installation,
- durability,
- a long service life.

To this end, we propose our Environmental Vision (Envision) system leveraging Artificial Intelligence (AI)-driven wireless sensing technologies for cargo ship container fire detection. Specifically, the system examines the wireless signal changes in the form of WiFi Channel State Information (CSI) as they propagate through the cargo hold and identify abnormal patterns caused by fire or rapidly rising temperature using AI, analogous to radars. Due to the multipath propagation characteristics of the wireless signals, that is, transmitted wireless signals propagating through multiple different paths in space before arriving at the receiver, it is possible to cover an entire cargo hold with only a small number of wireless sensors.

2 Methodology

2.1 Proposed System

The proposed Envision system comprises a dual-part architecture: a hardware component equipped to gather essential radio signal attributes, specifically WiFi CSI, and a software component designed for signal analysis and predictive modelling as shown in Figure 1. This system utilises WiFi signals for operation, and the hardware is built from off-the-shelf components, including Raspberry Pi computers and ESP32 microcontrollers. The Raspberry Pis, powered externally, serve as the central receivers for transmissions from the ESP32s. All software for filtering, predictive algorithms, and the management system reside on the Raspberry Pis. It may be noted that using ESP32s as the transmitters helps in a longer battery life, and Raspberry PIs acting as CSI receivers or extractors can be conveniently located near the power supply to carry out the desired signal processing and prediction. The software component of the system features filters to remove undesirable noise and elements from the extracted WiFi CSI data, and AI-based cargo hold temperature prediction and fire detection. This software analyses the rate of change in the CSI signals to determine the typical operational baseline. Any divergence from this established norm is used to identify and signal unusual activities, in this case, potential fire hazards.

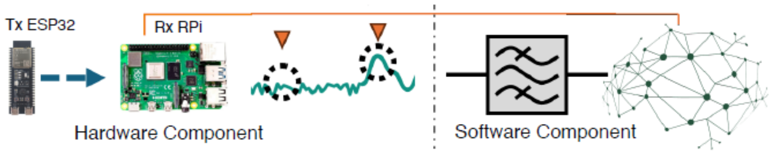


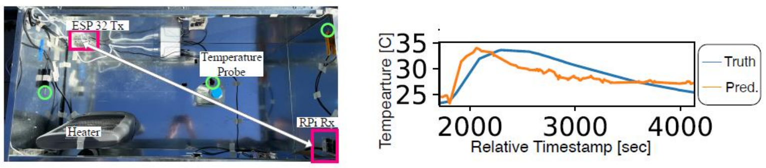
Fig. 1: Proposed System Architecture

Envision technology offers a multitude of advantages. Its sensors are highly cost-effective and designed to be effortlessly enclosed for environmental protection. The simplicity of their installation and upkeep is notable, as they do not require any adjustment or cleaning post-installation. Furthermore, they operate without the need for direct line-of-sight, eliminating the necessity to orient the sensors towards a specific target area. This is particularly significant in closed environments like cargo holds where containers are stacked, and the sensing technology needs to work without relying on the clear sight of the entire target region. For on-board installation, we designed and produced our wireless sensor hardware ruggedised, and housed in specialised IP57-rated housing. The Envision sensor system will consist of four sensors, and the software will raise an alarm when a fire event is predicted or detected.

2.2 Simulated Cargo Hold Validation

To validate the Envision sensing solution for early-stage fire detection in cargo holds, a simulated cargo hold was used for various experiments. These tests demonstrated that the Envision sensor system could learn from its environment, predict fire onset accurately, track the changes due to increased fire intensity, and provide and integrate with a dashboard for real-time operational insights.

Specifically, we simulated a cargo hold using a metal trunk (1050mm x 365mm x 392mm). The metal trunk mimicked the metallic shell of a cargo hull as shown in Figure 2a. The metal trunk was instrumented with WiFi sensors and thermal probes. The WiFi sensors, along with thermal probes, were installed inside the trunk to monitor the temperature. The probes provided baseline temperature data, while a combination of a heater and charcoal fire beads created thermal events, simulating the conditions that might occur inside a real cargo hold.



(a) Setup (b) Evaluation Result

Fig. 2: Simulated Experiment

To validate the system's functionality, a set of tests were carried out. These tests involved activating and deactivating a heater, lighting charcoal fire beads to simulate fires and pinpoint their origins, moving the trunk across various terrains to mimic vibrations, and situating radio-transmitting devices inside and around the trunk to assess interference. Moreover, the Envision sensor system was successfully integrated with the popular sensor dashboard, Things Board, showcasing its compatibility with standard dashboard systems. As shown in Figure 2b, the outcomes of the tests provided definitive evidence of the Envision sensing system's capability to detect initial fire outbreaks and ongoing fire conditions. When measured against the temperature probes, the system's forecastsm were found to be extremely precise, mirroring the actual temperature measurements closely with errors of less than 1 degree Celsius. The trials also confirmed the Envision capability for in-situ learning to adapt to the environmental conditions once set up within the metal trunk. Moreover, it showcased the system's proficiency in localising the source of fire to a specific area within the mock setup. Additionally, the system's performance remained unaffected by external factors, such as vibrations, radio frequency disturbances, or the proximity of other radio-emitting devices. The system also boasts a remarkable sensing precision, achieving fire detection accuracy within the 99th percentile, which corresponds to an extremely low rate of both false positives and false negatives. This high level of accuracy and dependability can be further enhanced by simply adding more sensors to the network. Additionally, the resolution of the Envision sensing technology can be customised based on the trade-off between quality of service and deployment costs. Moreover, the system is designed to be scalable, with the capacity to incorporate additional features and functionality through software upgrades, all without the need to alter or replace the already deployed one.

2.3 Real-World Validation

Further, to demonstrate the real-world applicability of the proposed Envision sensing technology, we experimentally verified it on actual cargo ships in two separate trials with Evergreen and ONE. As a result, these trials validated the functionalities of the proposed Envision wireless fire detection technology by confirming the operation and wireless signal coverage on the cargo ships.

3 Significance

Emerging on-board fire detection technologies include fibre-optic Linear Heat Detection (LHD), sensor-based LHD, Internet-of-Things Networks, Infrared cameras, as well as wireless sensing techniques. However, only wireless sensing is able to satisfy all the aforementioned requirements. Specifically: 1. Fibre optic LHD is expensive and demands complex maintenance and installation, while providing no localisation capability. It is also fragile due to the nature of fibres; 2. Sensor-based LHD provides some localisation potential and costs relatively less than fibre optics, but still requires complex installation; 3. IoT networks are similar to Sensor-based LHD in terms of localisation and installation complexity, while costing less; 4. Infrared cameras could provide good localisation functionality, but suffer from high cost and are prone to damages caused by the harsh environment with limited service life; 5. Traditional gas sensors also suffer from a lack of localisation capability and high installation complexity and cost; 6. WiFi sensing-based Envision technology is capable of detecting and localising the onset of fires in a timely fashion while maintaining low costs and easy installation options.

4 Conclusion

In conclusion, our successful simulated cargo hold testing and real-world trials demonstrated the potential of our proposed Envision fire detection technology to significantly enhance maritime safety through the early detection and localisation of cargo hold fires. In addition, this technology has undergone trials in the Sydney Harbour Tunnel and holds potential for future expansion into transport tunnels and underground mines, thereby bolstering safety measures within these sectors.

Keywords: Safety in Logistics Services, Maritime Transportation, Fire Detection, Fire Localisation, Wireless Sensing

Tuesday, August 28, 13:00-14:30 h,
Session: Resilient Operations

Optimizing Maintenance Scheduling Considering Predictive Maintenance Inaccuracy

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Abstract. In this paper, a maintenance scheduling optimization model is developed and integrated into predictive maintenance to assess a timebuffer approach to mitigate prediction inaccuracy. A framework model is presented that shows the key terminology, performance indicators, and the relationship between the predictive models and the optimization model. The optimization model is applied in a case study, which demonstrates the influence of buffer times on the number of breakdowns and the gap between system demand and supply.

Keywords: Predictive Maintenance, Maintenance Scheduling, Optimization Model, Decision Support

Tuesday, August 28, 13:00-14:30 h,
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Improving Safety of Navigation and Sustainability of Shipping through Innovative Autonomous Shipping Technologies in Asia Pacific: Case Study of Thailand

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Research Background

The revolution of industry worldwide has affected the development of vehicles employed in all modes of transportation including the road, rail, air, and the shipping sector. The concept of autonomous vehicles has also extended to maritime vessels due to the potential of minimizing operational cost, removing the difficulties to hire crew members, reducing the discharge of garbage and sewage, and lowering the number of human error-induced incidents during the voyage mainly due to human exhaustion. The objectives of the paper are to (a) review the concept of autonomous shipping (b) explore lessons learned from stakeholders in Thailand on how they prepare for adopting autonomous vehicles and autonomous shipping; (c) evaluate opportunities, threats and the readiness of Thailand to engage in innovative autonomous shipping; and (d) propose guidelines for implementing autonomous shipping in Thailand. The study used qualitative methods and content analyses by collecting data from in-depth interviews and arranging focus groups comprising representatives from relevant private and public sectors involving in shipping operation, maritime regulation, and innovation development to obtain common conclusions.

Tuesday, August 28, 13:00-14:30 h,
Session: Resilient Operations

The Maritime Transport Situation in Thailand and the Motivation to Introduce Autonomous Vehicles and Vessels

Thailand has a coastline of 3,219 kilometers which is divided into two parts: the Thai Gulf and the Andaman Coast. The coastline of the Thai Gulf has al length of 1,660 kilometers distributed from the Eastern region, Bangkok and the surrounding area, the Lower Central region, the Upper Southern region, and the Lower Southern region. At the end of 2023, Thailand had a merchant fleet comprising 376 vessels with a capacity of over 500 gross tonnage which is equivalent to a total carrying capacity of 4.28 million deadweight tons. 55 percent of these are vessels carrying liquid cargo - mainly oil, gas, and chemical substances, while 45 percent are vessels carrying dry bulk, containerized products, and break-bulk cargo. All vessels are owned and managed by private companies. The main legislations concerning the maritime and waterborne transportation sector encompass the Navigation in Thai Waters Act, Thai Vessels Act, Carriage of Goods by Sea Act, General Average in Maritime Adventure Act, Preventing Ship Collision Act, Arrest of Ship Act, Multimodal Transportation Act, Port Authorities Act, and Customs Act. The Marine Department continues to be the sectoral regulator. It is in charge of law enforcement, navigation safety, ship registration and inspection, certifying a ship’s equipment and facilities, the maintenance of navigation channels, providing pilot services for seagoing vessels, a port construction and extension, and minimizing environmental impacts caused by navigation and port activities. It is also responsible for the promotion and development of maritime transport including infrastructure development.

The origin of Thailand’s interest in developing an autonomous vehicle industry began in 2015 as the automation industry was listed in one of the top-ten new-generation industries in Thailand's 4.0 policy. The government approved of three main mechanisms to build favorable ecosystems to propel the development of the automation system industry containing (1) the acceleration of all manufacturing and service industries to enhance efficiency by utilizing robotic and automation systems as well as to create local demand for the robot and automation industry; (2) the promotion of the production system integrator to ensure that the supply of SI will meet the demand; (3) the institution of the Center of Robotics Excellence to provide technological and advisory support for the existing robot and automation system enterprises to advance their operations to other planned products including autonomous vehicles, autonomous buses, robot taxis, autonomous ships, and autonomous aerospace vehicles. The main organizations in Thailand in driving the policy initiatives related to robots, autonomous vehicles, and the automation system industry are the Ministry of Industry and the Ministry of Higher Education, Science, Research and Innovation. nevertheless, the initadtive does not extend to the Ministry of Transportation. So far, Thailand has a limited implementation of automation in the shipping sector.

Challenges of Developing Innovative Autonomous Shipping

Up until now, the demand for autonomous shipping used for commercial transportation in Thailand is limited, which is opposite to the growing demand for environmentally friendly and clean energy vessels as well as the growing application of internet and digital communication in maritime shipping and port business. In order to commercialize autonomous vessels in the maritime transportation sector in Thailand, it is necessary to explore challenges in various aspects including *(a) Legal Concerns:* the limitation of navigation under existing Thai Water Act and Thai Customs Act which requires ship masters staying on board to inform the arrival and departure of the ship to relevant authorities including the marine department, port operators and custom authorities; *(b) Human Resource Concerns:* the current education and training programs and facilities offered in universities, vocational school, and training institutes have not yet catered to support the adoption of autonomous shipping. They put Thailand into a difficult position for properly preparing human resources in public and private sectors to accommodate the implementation of autonomous shipping in the short and medium term. The courses offered at universities and colleges specializing in maritime transport studies still focus upon conventional subjects such as cargo handling and stowage, ship communication, oceanographic prevention of marine pollution, advance ship passage planning, electronic navigation, celestial navigation, navigational watch keeping, ship stability, ship construction, seamanship, and cargo ship training; and *(c) Cybersecurity Concerns:* cybersecurity problems arise when the vessel begins to utilize digital systems based on computer programming. Autonomous vessels are especially vulnerable to cyber threats, as they heavily rely on complicated computerized systems, large data transfers through satellite links and satellite navigation. Without navigational information, the vessels cannot continue their voyage. Unmanned vessels controlled from the shore and fully autonomous vessels that are remotely controlled, when required, depend largely on the exchange of large amounts of information via a satellite link. Disrupted communication or false information may lead to a total loss of control.

Guidelines of Implementing Autonomous Shipping in Thailand

Based on information gathered through the survey and focussing on the group to obtain a common pathway to successfully implement autonomous shipping in Thailand, the paper proposes pragmatic measures to promote autonomous vessels in Thailand in the medium to long term as follows: *(1) Establishing a forum on autonomous vessels* to raise awareness and strategies to promote the progressive adoption of autonomous vessels in domestic and international water territory. It is of special importance to incorporate representatives of themarine transportation sector in working teams to promote robots, autonomous vehicles, and the automation system industry which is now headed and mostly governed by representatives from the Ministry of Industry to reduce the development gap and to accelerate the progress of inventing and commercializing autonomous vehicles used in the transportation sector; *(2) Opening Mindsets:* the philosophy of launching autonomous vessels into commercial services to save cost and energy should predominantly focus on the safety management of operations, design, construction, and the liability to stakeholders while relevant stakeholders should open their minds to accept new technological advancements; *(3) Innovating education and human resource training and development:* the current education courses offered at universities, colleges, and training institutes in the country remain the focus of conventional maritime transport subjects, yet are not innovative enough to cater changing technological advancements such as robotic, digitalization, and future mobility, and other disruptive innovations; *(4) Experiments in a Closed System (Sandbox)* must be executed to ensure the commercialization of autonomous vessels by designating a specific area ofThailand's water territory for the experiment in the context of domestic and international navigation by starting to conduct a pilot project on a low-density route to ensure that the operationalization of the pilot run is safe; *(5) Modernizing Regulations:* the government should prepare to modernize or introduce regulations related to autonomous vessel design and construction, ship licensing, ship owner and ship controller licensing and qualification, safety management, safety assurance, cybersecurity, ship registration, and ship navigation in water territory, by relying on the facts discovered in the sandbox experiment, if applicable; and *(6) Creating a Technological Platform:* the government should consider the establoishment of a technological platform to monitor and communicate with autonomous vessels and ship owners/controllers as well as a ship reporting system for cases of emergency or collision, for ship arrival and departure times to/from ports, and the liability for ship owners/controllers to relevant stakeholders.

Keywords: Autonomous Shipping, Safety of Navigation, Sustainability, Thailand

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Smart Terminals II

Wednesday, 28.08.2024, 13:00-14:30, Room 122

Chair:Hans-Dietrich Haasis

Berth Allocation with Integrated Cold Ironing at Maritime Container Terminals: Mathematical Modelling and a Matheuristic Approach:
Abtin Nourmohammadzadeh, Stefan Voß

A Bi-Level Model for Locating Intermodal Container Terminals Using the Entropy Maximization Approach:
Jiajie Zhang, Yun Hui Lin, Ek Peng Chew, Kok Choon Tan

The Container Assignment Model: An Efficient Three-Stage Solution Method:
Michael Bell, Veronica Schulz, Shengda Zhu, Jyotirmoyee Bhattacharjya, Glenn Geers

Tuesday, August 28, 13:00-14:30 h,
Session: Smart Terminals II

Berth Allocation with Integrated Cold Ironing at Maritime Container Terminals: Mathematical Modelling and a Matheuristic Approach

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Abstract. Efficient berth allocation at container terminals is critical for minimising vessel turnaround times and optimising port operations. Considerations need to be given to various environmental issues including cold ironing (also known as shore power or shore-to-ship power or shore-side electricity), which is the process of providing electrical power to a ship at berth from the shore. This paper addresses the berth allocation problem in a port equipped with cold ironing facilities, where allocation decisions must consider both the location of these facilities and the preferences of the vessels. Our objective is to minimise the total berthing delay, the deviation from preferred berthing locations, and the distance to the nearest electrical connection.

To cope with this problem, we develop a mathematical model that captures the complexities of berth allocation in the presence of cold ironing requirements. Given the complexity of the problem, we propose a matheuristic approach that combines Variable Neighbourhood Search with the Partial Optimisation Metaheuristic under Special Intensification Conditions (POPMUSIC). This hybrid method efficiently explores the solution space and intensifies the search in promising regions, thereby providing high-quality solutions within a practical time frame. Our results demonstrate that the proposed approach effectively balances operational efficiency with environmental considerations, making it a valuable tool for modern port management.

Tuesday, August 28, 13:00-14:30 h,
Session: Smart Terminals II

Keywords: Berth Allocation, Cold Ironing, Mathematical Modelling, Matheuristics Variable, Neighbourhood Search (VNS), Partial Metaheuristic Optimisation Under Special Intensification Conditions (POPMUSIC)

A Bi-Level Model for Locating Intermodal Container Terminals Using the Entropy Maximization Approach

Jiajie Zhang[1a], Yun Hui Lin[2], Ek Peng Chew[1], Kok Choon Tan[1]

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1 Introduction

One solution to alleviate port congestion due to the soaring demand of containerized trade is to optimally locate intermodal container terminals (IMTs). In fact, the use of IMTs can reduce not only port congestion, but also transportation costs and greenhouse gases (Soloviova et al., 2020). Locating IMTs has aroused increasing attention in recent years (see Teye et al. (2017, 2018), Abareshi & Zaferanieh (2019)). In this paper, we consider a 'leader-follower' game for locating open-access IMTs in a port city. We also involve the design of IMT capacities from a set of discrete capacity levels. Here,'open-acess' means that the IMTs are free to be used for all the shippers (Teye et al. 2017, 2018). We have two players in the network, 'the leader' - the operator of IMTs and 'the follower' – the shippers. The leader needs to jointly decide the location and (discrete) capacity levels of IMTs, while the shippers decide how to route their containers in the network to serve demand zones. We employ the entropy maximization principle (EM) to depict the follower's (shippers) route choice behavior. This has two benefits. First, this principle yields the least unbiased distribution of flows (Jaynes, 1957); second, this principle can deal with capacitated facilities which is intractable for other choice models, such as multinomial logit (MNL). As such, EM is a good fit for the location and capacity design problems. Based on this, we build a bi-level model where the leader wants to locate a set of IMTs to maximize its profit, and the follower responds to the leader's decison by making route choices following the entropy maximization principle.

2 Problem Formulation

In this section, we present a detailed description of the IMT location problem followed by a bi-level program formulation. Main notations are given in Table 1, and additional ones will be introduced whenever necessary.

We first introduce the concept of entropy in an intermodal network. Let Y_{ij} denote the proportion of containers transported through IMT $j \in J$ to demand zone $i \in J$ and Z_i denote the proportion of containers transported directly from the sea port to demand point $i \in I$.

Sets	
J	Set of candidate intermodal container terminal locations.
I	Set of hinterland demand zones.
K	Set of capacity levels.
L	Set of all planning decisions of the IMT operator $\|L\| = \|J\| \times \|K\|$.
Parameters	
a_{jk}	Capacity of intermodal terminal $j \in J$ with capacity level $k \in K$.
f_{jk}	Fixed cost of opening intermodal terminal $j \in J$ with capacity level of $k \in K$.
r_j	Unit service fee charged to users for using intermodal terminal $j \in J$.
q_i^{ip}	Import demand of zone $i \in I$.
q_i^{ep}	Export demand of zone $i \in I$.
q_i	Total import and export demand of zone $i \in I$, i.e. $q_i = q_i^{ip} + q_i^{ep}$
c_{ij}	Unit cost for routing containers from intermodal terminal $j \in J$ to demand zone $i \in I$.
t_i	Unit cost for routing containers directly to demand zone $i \in I$.
B	System's total transportation budget.
Decision Variables	
X_{jk}	Binary. 1 if intermodal terminal $j \in J$ is open with capacity level $k \in K$; 0 otherwise.
Y_{ij}	Nonnegative. The fraction of containers transported through IMT $j \in J$ to demand zone $i \in I$.
Z_i	Nonnegative. The fraction of containers transported from the sea port to demand zone $i \in I$.

Table 1 – Main Notations.

Since the import and export processes are inverse to each other, we define $q_i=q_i^{ip} + q_i^{ep}$ as the total demand of each demand zone $i \in I$. The total demand in the network is $Q=\sum_{i\in I} q_i = \sum_{i\in J} q_i Y_{ij} + \sum_{i\in I} q_i Z_i$. Then the entropy in the network is defined as

$$E = \frac{Q!}{\prod_{i\in I}\prod_{j\in J}(q_i Y_{ij}!)\prod_{i\in I}(q_i Z_i!)}. \tag{1}$$

Taking the natural logrithm of both sides of (1) yields

$$\ln E = \ln Q! - \sum_{i\in I}\sum_{j\in J} \ln q_i Y_{ij}! - \sum_{i\in I} \ln q_i Z_i!. \tag{2}$$

Next, applying the Stirling's approximation to (2), we have

$$\ln E = \ln Q! + \sum_{i\in I}\sum_{j\in J}[q_i Y_{ij}(1-\ln q_i Y_{ij}) - 1] + \sum_{i\in I}[q_i Z_i(1-\ln q_i Z_i) - 1]. \tag{3}$$

Note that maximizing E is equivalent to maximizing lnE, and the total demand Q is a constant. Therefore, the following objective arises

$$\sum_{i\in I}\sum_{j\in J} q_i Y_{ij}(1-\ln q_i Y_{ij}) + \sum_{i\in I} q_i Z_i (1-\ln q_i Z_i) \tag{4}$$

$$= \sum_{i\in I}\sum_{j\in J} q_i Y_{ij}(1-\ln Y_{ij}) + \sum_{i\in I} q_i Z_i (1-\ln Z_i) - \sum_{i\in I}(\sum_{j\in J} Y_{ij} + Z_i) q_i \ln q_i \tag{5}$$

We can directly drop the last term; because it is a constant since the summation of flow proportion is 1, i.e., $\sum_{j\in J} Y_{ij} + Z_i = 1, \forall i \in I$. The remaining part is the entropy function that we want to maximize.

Let X_{jk} denote the leader's location decision, where $X_{jk} = 1$ indicates that IMT $j \in J$ is open with capacity level $k \in K$ and 0 otherwise. Then the lower-level problem for flow estimation (or route choice prediction) models the interaction between the upper- and lower-level problems

$$\max \quad \sum_{i\in I}\sum_{j\in J} q_i Y_{ij}(1-\ln Y_{ij}) + \sum_{i\in I} q_i Z_i (1-\ln Z_i) \tag{6a}$$

[LLP] $$\text{s.t.} \quad \sum_{j\in J} Y_{ij} + Z_i = 1, \forall i \in I, \tag{6b}$$

$$\sum_{i\in I}\sum_{j\in J} q_i c_{ij} Y_{ij} + \sum_{i\in I} q_i t_i Z_i \le B, \tag{6c}$$

$$\sum_{i\in I} q_i Y_{ij} \le \sum_{k\in K} a_{jk} X_{jk}, \forall j \in J, \tag{6d}$$

$$Y_{ij}, Z_i \ge 0, \forall i \in I, \forall j \in J. \tag{6e}$$

Constraint (6b) imposes that the summation of containers transported to each demand zone $i \in I$ should satisfy the corresponding demand; Constraint (6c) imposes that the total transportation cost should be lower than the network users' total expected budget. For example, if the IMT network is not constructed, the users may incur the cost of $\sum_{i\in I} t_i q_i$.

The users may expect a lower transportation cost than this benchmark, meaning that a total transportation budget can be set at $B = \sum_{i\in I} t_i q_i$; Constraint (6d) imposes that the flows routed through each IMT $j \in J$ cannot exceed its handling capacity; it also ensures that if an IMT j is not open, then no flow can be routed through it; Constraint (6e) states that flows are non-negative. Now we return to the upper-level problem and model the IMT operator's decision as the following

$$\textbf{[ULP]} \quad \max \sum_{i\in I}\sum_{j\in J} q_i r_j Y_{ij} - \sum_{j\in J}\sum_{k\in K} f_{jk} X_{jk} \tag{7a}$$

$$\text{s.t.} \sum_{k\in K} X_{jk} \le 1, \forall j \in J, \tag{7b}$$

$$X_{jk} \in \{0,1\}, \forall j \in J, \forall k \in K. \tag{7c}$$

The upper-level objective (7a) denotes the IMT operator's profit earned by charging service fee for intermodal flows routed through IMTs, subtracting the cost of setting up IMTs; the upper-level constraints (7b) imposes that for each IMT $j \in J$, at most one capacity level $k \in K$ can be assigned. If no capacity level is assigned to some IMT $j \in J$, i.e. $X_{jk} = 0, \forall k \in K$, then the IMT is not open.

3 Exact Solution

We use a logic-based branch-and-cut framework to solve the model. Specifically, for any fixed $\bar{X}$ from **[ULP]**, let $(\bar{Y}, \bar{Z})$ be the corresponding flow by solving **[LLP]**. We define $S(\bar{X}) = \{j \in J : \sum_{k\in K} \bar{X}_{jk} = 0\}$ as the set of closed IMTs and $\Pi(\bar{X}) = \sum_{i\in I}\sum_{j\in J} q_i r_j \bar{Y}_{ij} - \sum_{j\in J}\sum_{k\in K} f_{jk}\bar{X}_{jk}$ corresponding profit under $\bar{X}$ Then the following logic cut (or integer L-shaped cut)

$$\sum_{i\in I}\sum_{j\in J} q_i r_j Y_{ij} - \sum_{j\in J}\sum_{k\in K} f_{jk} X_{jk} \le \left(\sum_{i\in I}\sum_{j\in J} q_i r_j - \Pi(\bar{X})\right) \cdot \left(\sum_{j\in S(\bar{X})}\sum_{k\in K} X_{jk} + \sum_{j\in J\setminus S(\bar{X})} (1 - \sum_{k\in K} X_{jk})\right) + \Pi(\bar{X}) \tag{8}$$

is valid for the bi-level model. We embed the above cut into a branch-and-cut tree, which is added as lazy constraints (if violated) in integer nodes in the tree. Table 2 reports the computational results on 18 synthetic instances. t[s] refers to the computational time, #N refers to the number of explored nodes in the branch-and-cut tree and #C refers to the number of cuts added. Our exact solution approach can solve instances with 100 demand zones, 30 candidate IMTs and 5 candidate capacity levels within 1h.

Instance NO.	$\|I\|$	$\|J\|$	r	$f_{\|K\|}$	$a_{\|K\|}$	t[s]	#N	#C
1	50	10	U[30,50]	U[50000,100000]	U[1400,2000]	4.42	1	3
2	50	10	U[30,50]	U[55000,95000]	U[1300,2000]	3.65	1	4
3	50	10	U[40,50]	U[50000,100000]	U[1400,2000]	35.12	450	52
4	50	10	U[40,50]	U[50000,100000]	U[1300,2000]	46.01	607	65
5	50	10	U[40,50]	U[55000,95000]	U[1400,2000]	48.3	656	66
6	50	10	U[40,50]	U[55000,95000]	U[1300,2000]	23.61	210	34
7	50	20	U[30,50]	U[50000,100000]	U[1400,2000]	6.59	1	4
8	50	20	U[30,50]	U[50000,100000]	U[1300,2000]	13.12	1	6
9	50	20	U[30,50]	U[55000,95000]	U[1400,2000]	16.9	26	9
10	50	20	U[30,50]	U[55000,95000]	U[1300,2000]	22.57	34	13
11	50	20	U[40,50]	U[50000,100000]	U[1400,2000]	2086.99	42243	1037
12	50	20	U[40,50]	U[50000,100000]	U[1300,2000]	876.94	3982	492
13	50	20	U[40,50]	U[55000,95000]	U[1400,2000]	917.4	3605	516
14	50	20	U[40,50]	U[55000,95000]	U[1300,2000]	736.32	3290	414
15	100	30	U[30,50]	U[50000,100000]	U[1400,2000]	1394.49	11951	530
16	100	30	U[30,50]	U[50000,100000]	U[1300,2000]	430.93	2325	168
17	100	30	U[30,50]	U[55000,95000]	U[1400,2000]	1810.85	7087	680
18	100	30	U[30,50]	U[55000,95000]	U[1300,2000]	365.06	1320	135

Table 2 – Computational results on synthetic instances

Keywords: Intermodal Container Terminal, Entropy Maximization, Bi-Level Program, Facility Location, Capacity Design

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Tuesday, August 28, 13:00-14:30 h,
Session: Smart Terminals II

Teye, Collins, Bell, Michael GH, & Bliemer, Michiel CJ. 2018. Locating urban and regional container terminals in a competitive environment: An entropy maximising approach. Transportation Research Part B: Methodological, 117, 971–985.

Tuesday, August 28, 13:00-14:30 h,
Session: Smart Terminals II

The Container Assignment Model: An Efficient Three-Stage Solution Method

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Abstract. Previous work on the container assignment problem combined the assignment of full containers to hyperpaths with the repositioning of empty containers in a single linear program. The container assignment principle followed the Spiess and Florian transit assignment hyperpath principle, whereby containers are assigned to optimal paths according to the arrival time of the container and ship. To avoid solving a large linear program for transit assignment, Spiess and Florian developed a variant of Dijkstra's shortest path algorithm. While this is applicable to full containers, it was believed that empty containers could not be repositioned in the same way because of the absence of an empty container origin-destination matrix. Empty containers are assigned from surplus ports to deficit ports to minimize expected repositioning time. This paper shows that the empty containers can be assigned to the same hyperpaths as the full containers when a balanced transportation problem is solved to yield an origin-destination matrix for empty containers. This leads to a three-stage procedure, whereby the hyperpaths are first built, then a balanced transportation problem is solved to obtain an origin-destination matrix for empty containers, and finally, full and empty containers are assigned to the hyperpaths separately or together. A novel scheme to ship cargo in 'meter cube' boxes by Sydney's ferries is presented to illustrate the three-stage procedure.

Tuesday, August 28, 13:00-14:30 h,
Session: Smart Terminals II

Keywords: Container Assignment, Empty Container Repositioning, Frequency-Based Assignment, Hyperpaths, Ferries

Smart Ports II

Wednesday, 28.08.2024, 15:00-16:30, Room 121

Chair:Ding Yi

Metaheuristic Approaches for the Straddle Carrier Dispatching Problem:
Ahmet Cürebal, Nina Radojičić, Leonard Heilig, Stefan Voß

Machine Learning-based Transport Time Prediction in Container Terminals:
Julian Neugebauer, Leonard Heilig, Stefan Voß

Metaheuristic Approaches for the Straddle Carrier Dispatching Problem

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Abstract. The straddle carrier (SC) dispatching problem is an optimization problem in container terminals, where SCs transport containers between the yard and the sea-side area to enable the loading and unloading of containers by quay cranes. Given the role of SCs and the importance of efficient container flows, this problem has significant potential to impact the overall productivity of terminals. The problem involves determining the routes for SCs by assigning containers to each SC and establishing the sequence in which each SC processes its assigned containers. In this work, we address the problem using real-world data and apply various metaheuristics, such as two variants of Variable Neighborhood Search (VNS) and Greedy Randomized Adaptive Search Procedure (GRASP), to solve the problem and compare their performance. Numerical experiments show that the proposed methods deliver competitive improvements over given initial solutions, with VNS variants yielding superior results. The resulting dispatching allows for faster vessel turnaround times by reducing the idle times of quay cranes, thereby improving their efficient usage.

Keywords: Vehicle Dispatching, Port Logistics, Container Terminals, VNS, GRASP

Tuesday, August 28, 15:00-16:30 h,
Session: Smart Ports II

Machine Learning-based Transport Time Prediction in Container Terminals

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Abstract. Transport times in container terminals have been widely studied, often with a focus on automated vehicles, while manual operations remain prevalent in many ports. Predicting transport times for straddle carriers in container terminals is a challenging problem, while contributing to the accuracy of planning and thus impacting efficiency and productivity of manual container handling. In this paper, we propose a machine learning-based method for predicting transportation times, leveraging a unique dataset obtained from a digital twin. The dataset is sourced from the EUROGATE Container Terminal Hamburg, Germany, and incorporates positional and operational data from the straddle carriers. Our method demonstrates superior accuracy and performance compared to conventional methods, tailored to the needs of manual container handling. The conducted research provides insights on factors having an important impact on the performance of straddle carriers and discusses possibilities to integrate the approach for optimizing container terminal operations.

Keywords: Travel Time Prediction, Machine Learning, Container Terminal, Digital Twin

Environmental Sustainability

Wednesday, 28.08.2024, 15:00-16:00, Room 122

Chair: Haobin Li

Optimizing Maritime Logistics for Ocean Alkalinity Enhancement:
Martine Lindland, Emmiche Advocaat Wigand, Kjetil Fagerholt, Frank Meisel, Lisa Herlicka

Employing System Archetypes to Facilitate Decision-Making in the Transition to Alternative Marine Fuels at the Port of Singapore:
Hongdan Chen, Vedpal Arya, Haobin Li, Yanan Li

Tuesday, August 28, 15:00-16:00 h,
Session: Environmental Sustainability

Optimizing Maritime Logistics for Ocean Alkalinity Enhancement

Martine Lindland[1], Emmiche Advocaat Wigand[1], Kjetil Fagerholt[1], Frank Meisel[2a], Lisa Herlicka[2]

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Abstract. To address the increasing need to limit global warming and greenhouse gas emissions, multiple approaches must be employed simultaneously. Although there has been a historical emphasis on reducing overall emissions, there is now a growing interest in technologies directed at removing or capturing already-released CO_2 from the atmosphere. Ocean Alkalinity Enhancement (OAE) is one of these technologies, where alkaline minerals such as limestone are dispersed in seawater in order to enhance natural chemical processes and increase the uptake of CO_2 by the ocean. In this context, this paper presents a mathematical optimization model for the Ship-Based Maritime Alkalinity Distribution Problem (SMADP). The problem aims to maximize the net uptake of CO_2 by efficiently distributing limestone in the sea through a fleet of dedicated vessels. To assess this, we consider both the CO_2 uptake from the limestone distributed and the emissions associated with the ships deployed when deciding on the area to service by the ships, the optimal sailing speed, and the discharge rate for the minerals. Our computational experiments show that some model parameters such as ship sizes or uptake factors can have a substantial impact on the effectiveness of the fleet operations. Nevertheless, in all considered scenarios a substantial net uptake of CO_2 can be achieved and our cost estimates indicate that OAE is economically competitive to other negative emission technologies.

Keywords: Ocean Alkalinity Enhancement, Mineral Distribution, Maritime Logistics, Optimization Model, Abatement Cost Estimate

Tuesday, August 28, 15:00-16:00 h,
Session: Environmental Sustainability

Employing System Archetypes to Facilitate Decision-Making in the Transition to Alternative Marine Fuels at the Port of Singapore

Hongdan Chen, Vedpal Arya[a], Haobin Li, Yanan Li

National University of Singapore, Singapore

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1. Introduction

The maritime industry, responsible for 2.89% of global anthropogenic GHG emissions, is at a pivotal point, driven by the International Maritime Organization's (IMO) ambitious targets. The IMO aims to reduce GHG emissions by at least 20% by 2030 and 70% by 2040, relative to 2008 levels. Additionally, the guidelines aim to decrease the carbon intensity of international shipping by at least 40% by 2030 compared to 2008, with a goal of achieving net-zero GHG emissions by around 2050 (IMO, 2023). Given the limitations of technological and operational improvement to achieve low carbon shipping, a transition from traditional marine fuels (TMF) such as low sulfur fuel oil and diesel, into alternative carbon-neutral or net-zero fuels, collectively referred to as alternative marine fuels (AMF) in this paper, including renewable methanol, hydrogen, and ammonia, is inevitable (Xing et al., 2021). In 2023, the Singapore bunker market, which comprises 36% of the global market with sales of 51.82 million tonnes, highlighted its crucial role in the shift towards alternative marine fuels (AMF) (Shaw Smith, 2023). However, significant challenges arise, particularly in updating the port's infrastructure to accommodate AMF demand surges (MPA, 2022). Despite likely sufficient investment from the Singaporean government, our study uses a system thinking approach to highlight the need for timely and early strategic investments to mitigate delays in infrastructure and regulatory development.

The use of systems thinking to comprehend the dynamics of the maritime industry has become increasingly popular, in areas such as port handling process, port economics, freight rates and other strategic policy problems (Oztanriseven et al., 2014). It is particularly useful for unravelling the supply and demand dynamics that confound modern maritime systems (Ng & Lam, 2011). However, its application in the transition to AMF has not yet been explored. Current literature on AMF focuses on evaluating their GHG reduction efficiencies and future economics but lacks research that considers the port, vessel, bunker supply and demand, environmental consequences as an integrated system from a higher-level perspective. Through our system dynamics model simulation, we integrate the system considering its internal interdependencies and feedbacks. By applying general system archetypes, we highlight potential consequences of inadequate bunker service capacity, such as prolonged vessel queuing times, and the subsequent need for the vessels to speed up to meet schedules (MPA, 2022). These issues compromise environmental goals and risk diverting business to competitive international ports potentially undermining Singapore’s status as a premier global refuelling hub (Lam et al., 2011). By anticipating barriers and recommending proactive infrastructure development, our analysis aims to ensure that the Port of Singapore can sustain its leadership in the maritime industry while advancing towards a sustainable, low-carbon future.

2. Methodology

In our study, we employ system dynamics to analyse the transition to alternative marine fuels (AMF) at the Port of Singapore. This approach is structured around three core system archetypes. Starting with the "Limit to Growth" archetype as the foundational model, we extend our analysis to include "Growth and Underinvestment" and further expand to "Fixes that Fail" to cover a broader range of challenges. Each archetype is modelled using Stock-and-Flow Diagrams (SFDs) that incorporate available public datasets and hypothetical scenarios to predict potential outcomes. This approach allows us to simulate various future scenarios under different assumptions, providing insights into potential challenges. The "Limit to Growth" system archetype, highlighted in pink in Figure 1, illustrates how initial successes in adopting AMF may trigger rapid growth in bunker demand in the Port of Singapore. However, this growth may eventually hit systemic limits in bunker service capacity, thereby stifling further expansion.

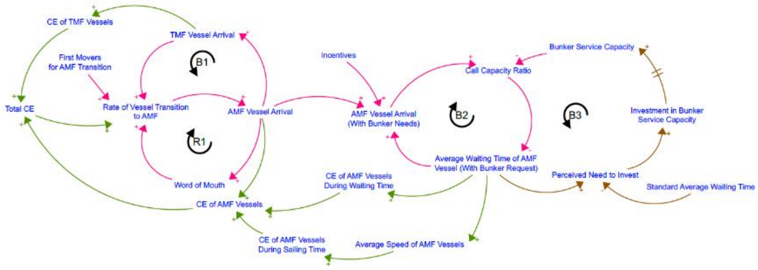

Fig.1: Causal Loop Diagrams for AMF Transitions

The "Growth and Underinvestment" archetype, represented by both pink and brown in Figure 1, focuses on the risks of AMF demand growth being compromised by delayed or insufficient investment in bunker service capacity. The simulation shows how such delays can create bottlenecks, such as extended queuing times, which in turn reduce bunker demand and discourage further investment. This cycle highlights the urgency of proactive investment strategies to circumvent underinvestment pitfalls. The "Fixes that Fail" archetype, encompassing the entirety of Figure 1, examines solutions that seem initially effective but may lead to negative outcomes due to unintended consequences. In the context of AMF adoption, while the goal is to directly reduce carbon emissions, inefficiencies from slow capacity expansion could lead to longer waiting times. Consequently, this may force vessels to increase their speed to maintain schedules, paradoxically boosting carbon emissions despite the transition to cleaner fuels (Fagerholt et al., 2010). The preliminary SFD for the "Fixes that Fail" system archetype, which is the most comprehensive of the three, is presented in Figure 5 to illustrate the complex dynamics.

3. Preliminary Result

The system dynamics simulation model covers the period from 2019 to 2050, aligning with the IMO target phases for emission reduction. As illustrated in Figure 2, the model assumes a constant annual growth rate for the total gross tonnage of vessel arrivals at the Port of Singapore, continuing the trend from 2013 to 2023 as documented by MPA (MPA, 2023), and projects this trend through to 2050. The model aligns the transition from traditional marine fuel (TMF) vessels to alternative marine fuel (AMF)vessels with global energy consumption patterns forecasted by the IEA (IEA, 2020), ensuring that the percentage of AMF usage corresponds with these forecasts.

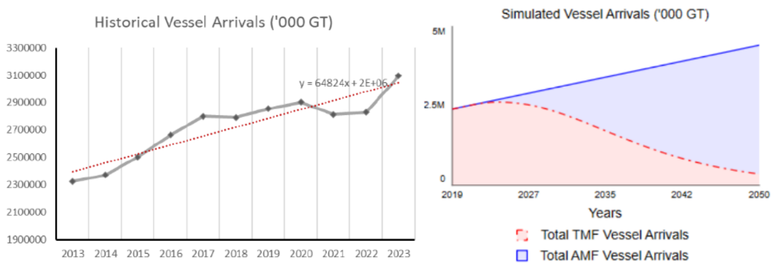

Fig.2: Historical Vessel Arrivals at the Port of Singapore (left) and The Simulated Result (right)

The variable “AMF carbon reduction efficiency” is defined as the average decarbonization effectiveness of the mix of AMFs adopted by the industry, compared with TMF. IMO expects a 40%- reduction in the carbon intensity of international shipping by 2030 (IMO, 2023), with this reduction expected to increase further due to the shift towards carbon-neutral and zero-carbon fuels by 2050. This trend is illustrated in Figure 3 (left). The simulation model forecasts the CO_2 emission index for vessel arrivals at the Port of Singapore through to 2050, relative to 2008 levels, assuming no additional emissions from bunker service capacity shortages and maintaining bunker calls at approximately 70% of the total vessel arrivals (MPA, 2023).

The results, depicted on the right side of Figure 3, indicate that CO_2 emissions will peak in 2028 and later decline. When faced with challenges from inadequate bunker service capacity, a likely decrease in demand for bunkering services is anticipated due to longer vessel waiting time and strong competition from other regional ports, along with additional emissions due to prolonged queuing times and subsequent increases in vessel speed. Figure 4 presents a comparison of two simulated scenarios: one where bunker service capacity investment and expansion are sufficient, i.e. the expansion in the AMF service capacity is able to meet the growing demand, and another where they are insufficient. This comparison clearly illustrates that an insufficient expansion of AMF bunker service capacity can lead to a decrease in the total number of vessel arrivals requesting AMF bunkering, as depicted by the green area in the chart.

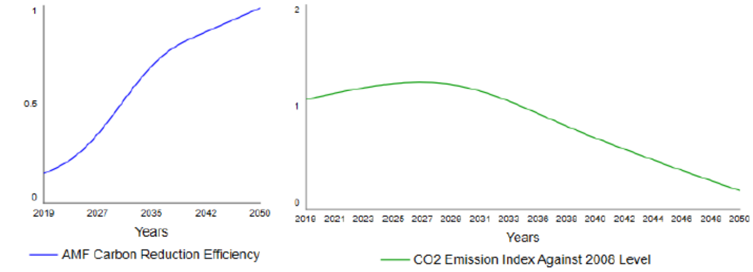

Fig.3: Carbon Reduction Efficiency of AMF and Simulated CO2 Emission Index Compared to 2008

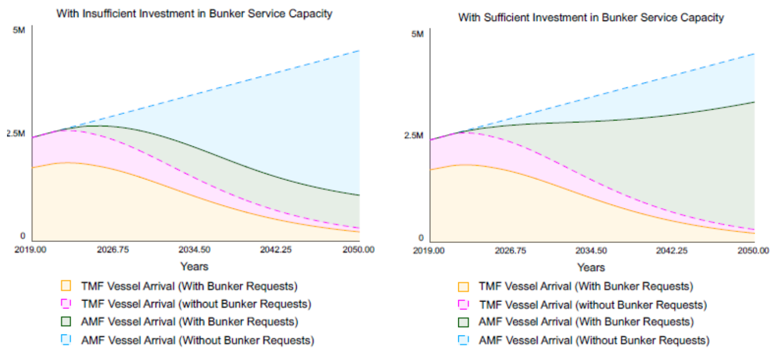

Fig.4: AMF Bunker Demand Projections with/without Sufficient Bunker Service Capacity Investment

The quantifiable impact of inadequate bunker service capacity on prolonged waiting times, subsequent increases in vessel speeds, and additional carbon emissions requires further validation. To confirm these effects, the model will be subjected to additional checks through sensitivity analysis to ascertain direct and indirect consequences of bunker service capacity on emissions.

4. Discussions

Building on the foundational work accomplished in the preliminary phases of our study on the transition to alternative marine fuels at the Port of Singapore, our future research agenda focuses on enhancing model validation, deepening the analysis and extending the scope of our models. The preliminary model validation is currently in progress and requires further consultation with experts to refine the problem statement and validate the model comprehensively. More stakeholder input is to be incorporated to confirm the model's accuracy and relevance. This includes, but is not limited to, validating the hypothesis regarding the constant annual growth rate of vessel arrivals in Singapore, the interdependent relationship among bunker service capacity, vessel waiting time, and the subsequent changes in bunker service demand. Moreover, our ongoing sensitivity analysis, which examines parameters and causal relationships under conditions of uncertainty, will be systematically concluded to enhance the robustness of our findings. Concurrently, the validation of data sources remains a critical step. This involves ensuring that data inherited from previous studies is not only suitable but also accurately applied to the current model, which necessitates updates and revisions in line with the latest model version. Finally, the verification of all model assumptions and a detailed assessment of policy impacts are slated to begin. These steps will evaluate how existing and proposed policies might affect the model outcomes, providing crucial insights for policymakers and stakeholders.

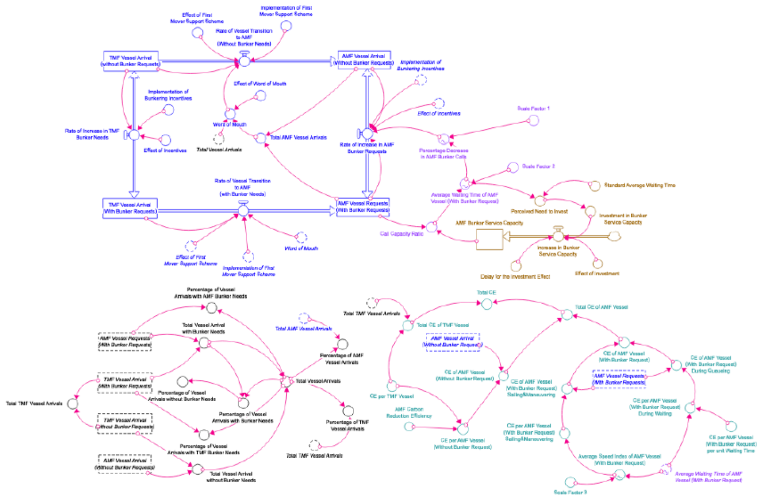

Fig.5: Fixes that fail SFD

Acknowledgement

The authors gratefully acknowledge the funding support from the Singapore Maritime Institute to conduct this research.

Keywords: Systems Engineering, Systems Modeling, System Dynamics, Maritime Decarbonization, System Archetype

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Keynote

Wednesday, 28.08.2024, 16:10-17:00, Room 221

Chair: Stefan Voß

Keynote by Dr. Jan Hoffman (UNCTAD)

Dr. Jan Hoffman joined the United Nations Conference on Trade and Development (UNCTAD) in 2003 and became Head of the organization's Trade Logistics Branch in 2016. The Branch is implementing multilateral transport and trade facilitation capacity building programmes, as well as regional and national projects in Africa, Asia and the Pacific, and Latin America and the Caribbean.

Dr. Hoffmann is co-author and coordinator of the annual UNCTAD Review of Maritime Transport, created and co-edits the quarterly Transport and Trade Facilitation Newsletter, and initiated the Maritime Country Profiles, the International Transport Costs Data Set, and the quarterly Liner Shipping Connectivity Index. Previously, he spent six years with the United Nations Economic Commission for Latin America and the Caribbean (ECLAC) in Santiago de Chile, and two years with the International Maritime Organization (IMO) in London and Santiago. Prior to this, he held part-time positions as assistant professor, import-export agent, seafarer, translator, and consultant. For eight years, he also worked part time for the family tramp shipping business Hoffmann Shipping, based in Horneburg, Germany, with a tweendecker registered in St. Johns, Antigua and Barbuda.

Dr. Hoffmann has studied in Germany, the United Kingdom, and Spain, and holds a doctorate degree in Economics from the University of Hamburg. His work has resulted in numerous UN and peer-reviewed publications, lectures, technical missions, databases, and electronic newsletters. He is member of AJSL, FFSC, IJSTL, INCU, JST, MEL, MPM, and the Propeller Club of Geneva. From 2014 to 2018, he was president of the International Association of Maritime Economists (IAME).

Wednesday, August 28, 16:10-17:00 h,
Session: Keynote

Digital Waves in Logistics and Maritime Systems: Sailing Towards Efficiency

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Abstract. Technological progress will never be as slow as it is today. As digitalization penetrates port and shipping services, it brings exponentially growing challenges and opportunities. This presentation will share the latest insights from UNCTAD reports and discuss ongoing research:

1. Long-term Trends in Digitalization of Trade and Maritime Transport
The COVID-19 pandemic provided a new impetus for digital reforms. Now, we must lock in the progress made during lockdown. The acceleration of digital cross-border trade procedures has improved efficiency and safety in trade operations. These digital transformations must be solidified to maintain their benefits.

2. Improved Maritime and Port Performance
Over the decades, performance indicators such as turnaround times, efficiency in customs procedures, and digital transaction processing have shown improvement. However, the Covid supply chain crisis interrupted these long-term positive trends. Are we now returning to the previous positive trajectory? Or are the Red Sea and other disruptions, plus the future energy transition putting breaks on this positive trend?

3. Increased Volatility
Could improved efficiency also lead to increased volatility? With more Just-In-Time processes, less redundant capacity, and faster responses due to expanding data availability, we discuss whether these efficiencies contribute to phenomena such as the recent

drastic surge in freight rates. While enhanced efficiency through digitalization leads to streamlined operations and cost savings, it also reduces buffer capacities, making systems potentially more susceptible to disruptions. This paradox and the recent extreme fluctuations in freight rates raise important questions about the resilience of our current models.

In Sum

As we sail towards greater efficiency in maritime logistics, it is crucial to lock in the progress made during the lockdowns, continuously evaluate our performance metrics, and strike a balance between efficiency and resilience to navigate future challenges successfully. The advancements in digitalization provide a pathway to a more efficient and responsive maritime transport system, but they must be carefully managed to ensure long-term stability and growth.