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Key challenges in digitalisation and data usage for maritime business and operations

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Within the maritime transport sector, data and information have the potential to change the way we work for the betterness. Increasingly shipping companies are generating, storing and reporting data, on their position, their engines, their products and their emissions. As a result, data is sometimes referred to as the new gold and people often protect it in the same way. However, unlike gold, data has actually more value when it is shared and used in collaboration with others.

Digitalisation and the use of data in shipping have an evolving history, building on various topics that started applying data analysis over the course of time. In relatively recent years, the topic of route optimisation has gained in relevance to ports, Szłapczyńska et al. (2022) developed an architecture of a weather routing system consisting of two key elements: onboard monitoring and route optimiser sub-systems. This was done to keep the client software as simple and light as possible. Borén et al. (2022) investigate the benefit of using weather ship routing optimisation, assessing the ship emissions for minimum distance routes and optimised routes. The expected increase of extreme weather events, in terms of frequency, intensity and duration due to climate change, suggests a gradual increase in benefits for implementing weather ship routing optimisation in all types of routes, regardless of the distance.

With respect to data usage in a way to avoid maritime accidents, Zhang et al. (2021) explore the spatial patterns and characteristics of maritime accidents on a global scale, using data from the Marine Casualties and Incidents (MCI) module of the Global Integrated Shipping Information System (GISIS). Distributions of mari-

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time accidents by time, initial event, and ship type are found to be diverse in different accident classes. Li et al. (2023) use the same GISIS database and find ship type, ship operation, voyage segment, deadweight, length, and power are among the most influencing factors.

Jia et al. (2020) use a maritime and port data analysis to incorporate the decision of pilot scheduling into the decision of vessel traffic management for congestion mitigation and vessel service enhancement. Wu et al. (2020) go a step further by examining a pilotage planning problem that involves decisions to schedule the vessel traffic in a seaport, assigning work shifts to pilots, and scheduling the pilots in each work shift for vessel navigation.

Concerning the issue of port transit time optimisation, Liu et al. (2022) start from the observation that the limited availability of berths and channels is generally the bottleneck restricting the capacity of a seaport and thus resulting in traffic congestion. Optimizing the operations of the berths and channels has been recognized as a more economical avenue for mitigating seaport traffic congestion compared with channel dredging and berth expansion which needs significant capital and time costs. Yang et al. (2021) developed a model for the optimization of the tramp ship scheduling to reduce the total operation cost, including the transportation cost and the unloading waiting cost, and the branch-and-price algorithm is adopted to solve this large-scale model.

Dredging is another topic where digitalisation and data analysis may support operations. Kaizer (2023) for instance developed an ECDIS simulator. Operational parameters are driving time, the time taken to fill a dredger, the manoeuvrability of the dredger and the determination of the safe distance between the dredger and other ships.

Panellists at the World Conference on Transport Research (WCTR) SIG A2 online conference in 2022 reported their point of view on the enhancement of vertical integration along supply chains and of horizontal integration among port stakeholder, when considering digital collaborations and data usage in maritime transport. One of the topics presented was the levels of machine digitalisation and the evolution process from Product Manufacturer to System Integrator. Next, the elements of virtual integration of the “vertical” chains for real-time visibility-tracking and the possibility of relating with “horizontal” chains were presented. This interest was brought further during the WCTR 2023 conference.

Considering the state of research as dressed above, and the observations made at the WCTR conferences, it seems useful to update the state of play on digitalisation and data analysis through a special issue.

1 Papers in this issue

Within this special issue, we’ll dive further into digitalisation and data analysis in relation to port operations and safety. A key source for information in these papers is AIS; five out of the eight papers presented use this source of information, yet applications widely vary between these papers. Estimated Time of Arrival (ETA), port performance and risks, are all derived from AIS data. We will treat these subjects after

each other, highlighting the contribution of each paper in the special issue linked to them. The recently published book of Notteboom et al. (2022) is reviewed by us as the last item of this Special Issue.

The uncertainty of the ETA of vessels has large impacts on the optimization of several port operations, such as pilotage, tug services and terminal operations. Two of the papers in this issue propose measures to improve the ETA using AIS data as input. The first paper, titled “[Data analysis for more accurate cargo ship ETA's: a model for ETA deviation prediction](#)” by Maervoet, Vanelslender and Vervoort, uses more traditional regression techniques. To examine which parameters have to be tackled primarily to reduce ETA deviations, this paper examines which parameters significantly influence ETA deviations. They do this for each individual ship type visiting the port of Antwerp. The equations developed on this basis are able to calculate the chance of ETA deviations for each vessel type in the dataset. This result allows all actors in the maritime supply chains to plan in a way that avoids unnecessary asset investment and staff costs.

The second paper on ETA is “[Deep Learning based Vessel Arrivals Monitoring via Autoregressive Statistical Control Charts](#)” by El Mekkaoui, Boukachab, Benabou and Berrado who turn their attention to AI and more specifically Deep Learning sequence models and Statistical Process Control Charts in order to track the variability in a vessel arrival process vessel. The proposed solution is a predictive deep learning model to get a vessel's estimated time of arrival. The model produces quality characteristics and applies statistical control charts to monitor their variability. This could make a significant contribution to operational measures aimed at reducing shipping emissions and optimizing resource utilization.

AI is also used in the third paper, titled “[How AI can influence efficiency of port operation specifically ship arrival process: developing a cost-benefit framework](#)” by Farzadmehr, Carlan and Vanelslender. It aims to optimise the arrival process, this time without the use of AIS. An exhaustive literature review is carried out, and a comprehensive framework is developed to identify the potential costs and benefits of using AI technologies in port operations. To validate this framework, a case study associated with ships' arrival process is investigated. The case study demonstrates that benefits gained by first adopters can stimulate similar companies to leverage the same solution for overcoming their challenges.

Besides optimisation of the arrival process, AIS can also be used to investigate port performance. The fourth paper, titled “[Attributes influencing port times of container ships](#)” by Russo, Pedà and Musolino, chooses this approach. In this case, the focus is on container flow handling. It investigates how the different attributes of the ports influence the port times of ships. The most important attributes are then discussed and a multiple linear regression model is estimated. The results obtained highlight the role of the attributes that affect the entire port system, such as ship capacity.

In the fifth paper, with the title of “[Transportation system models to analyse ports competition and cooperation](#)”, Russo and Musolino, take the comparison of ports to a higher level by developing a game theoretical model that for the first time takes into account congestion to understand the balance between competition and cooperation between close to each other ports. New forms of cooperation and competition took place at the same time, but at different levels (e.g. port versus terminal). The paper

presents a theoretical equilibrium model to analyse the competition and/or cooperation scenarios of two, or more, ports close to each other. This study allows both the impacts of alliance mergers and official port cooperation, and understand to what extent competition and cooperation play a key role in these efforts.

As mentioned in the first paragraph, AIS can also be widely used to identify areas of risk. This special issue contains two examples. Firstly, the sixth paper, “[A Risk Prediction Model for Maritime Accidents](#)” by Medda, Serra, Mandas and Fancello, investigates the use of machine learning to create a risk heat map for the Tyrrhenian area, a part of the Mediterranean with very heavy traffic, using an AIS snapshot. Using a global dataset on maritime accidents of dangerous goods from 2010 to 2019 (that includes information on the type of casualty, the location, the amount of material released, the type of material released, the cause of the accident, and the outcome), it applies both a machine learning technique and a statistical approach based on the Fourier distribution of rare events as a dual approach to address the problem. This could help both decision-makers and stakeholders to identify regions at risk of maritime accidents and take measures to prevent their occurrence.

In the seventh paper, “[Estimation of near-coastal bathymetry using AIS ship movements](#)”, Sederlin and Flötteröd, also use AIS data, but with a very different risk in mind, namely grounding. The cost of data collection as well as capacity constraints in the processing pipeline make reliable bathymetric information in some areas sparse. AIS is used to indicate drafts and shipping lanes in the Gothenburg archipelago. The method relies on viewing AIS draughts as censored observations of the true depth. Allowing the responsible authorities to focus their bathymetric soundings in critical areas and thus save costs.

The final paper is more technical than those described so far. Palma, Giglio and Tei, in their paper titled “[Investigating the influence of e-navigation and S-100 over the computation of the weather route](#)”, focus on the S-100 standard for e-navigation and investigate the possibility of including routings that include current data for the upcoming paths of the vessel. While interesting on its own, given the other directions investigated, it is easy to see even more possibilities, such as avoiding collision hotspots, improving ETA and relaying draft data in the future. This would lead to decreasing risks and increasing reliability for ports and ships.

2 Closing remarks

With this special issue, the guest editors hope to contribute further insights into digitalisation and data analysis as they are related to ports and shipping. We identified that AIS is a key source of inspiration for many researchers and their applications greatly vary, but all work towards reducing risks and increasing reliability. This is something that will help all partners in the supply chain, not only ports.

Although more traditional approaches are still in use, many researchers include machine learning and other AI tools to help them in their investigations. This leads to new possibilities and insights in comparison with standard statistical measures. These movements require data; we expect to see the collection and sharing of relevant data

become pivotal for shipping companies, port operators and all others in the maritime sector.

Finally, we are all grateful to those authors who submitted their valuable works to this special issue and to reviewers who spared their valuable time to ensure the quality to be in place for all the accepted papers in this issue. Professor Dong-Wook Song, the editor-in-chief, is duly appreciated for his commitment and facilitation from the beginning to this stage.

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