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SPECIAL ISSUE - AUTONOMOUS SHIPPING

Advances in maritime autonomous surface ships (MASS) in merchant shipping

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1 Introduction

Autonomous technologies have already been implemented successfully in several contexts such as container terminal operations, manufacturing systems, warehouse operations, transportation etc. In the transportation industry, Tesla pioneered self-driving cars with the autopilot function, diver-less metro-rail services functioning smoothly in the city of Copenhagen, while most airplanes fly on autopilot mode except for landing and take-off. Seaborne transportation is a rather latecomer in the autonomous technology scene. From a design and implementation perspective, maritime autonomous surface ships (MASS) is of course feasible, largely due to the presence of fewer physical objects (e.g., other vessels) in the high seas. Although, physical objects increase significantly when a ship is approaching a port, or it sails in coastal areas, they can still be dealt with through the implementation of advanced collision avoidance algorithms.

Formally, the development of MASS gained momentum after the Maritime Unmanned Navigation through Intelligence in Networks (MUNIN)[1] project was launched in 2012, in collaboration with eight partners from five European countries, partly funded by the European Commission. The project mainly investigated the feasibility of MASS through a case study of a dry bulk carrier. Since then, several MASS projects have been initiated by national and international organizations. The Norwegian Government funded several research projects on MASS development over the last decade, and several projects have also been funded by the European Commission in recent years.[2] Amongst the latter projects, AUTOSHIP is the

[1] Accessed on March 04, 2022 from www.unmanned-ship.org/munin.
[2] Accessed on March 04, 2022 from https://nfas.autonomous-ship.org/resources_page/projects-page/.

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largest one, having received 20 million EURO funding in 2019. In 2020, the Korean Government launched a MASS development project with a budget of 160 billion Won (approx. 132 million USD). The aim of the Korean project is to develop MASS that can be operated remotely without crew onboard, by 2025, in order to achieve at least 50% market share in the first wave of MASS commercialization. Recently, a group of Chinese universities and private companies have registered the majority of the patents related to autonomous ship technologies. In 2019, the Japanese shipping company NYK Line reported the successful completion of MASS voyage trials from Xinsha, China, to Nagoya, Japan, and a couple of days later from Nagoya to Yokohama. The company expects half of its fleet to be MASS by 2040. Further, Rolls-Royce demonstrated the feasibility of the first MASS ferry in December 2018, in collaboration with Finferries of Finland.

Given the pace of technological development and reported MASS trails in recent years, there is little doubt about the upcoming deployment of MASS in commercial shipping. As with every innovation in economic history, here too resistance to change is significant. In 2021, the International Longshoremen's Association (ILA) stated that they will not work on ships without crew onboard. Arguments have comprised safety, regulations, ship manoeuvring, ship-port interface, shore-control stations, and social implications (e.g., rising unemployment amongst seafarers). These and more were exemplified by the heated discussions, at a panel on autonomous shipping, of the 2021 annual conference of the International Association of Maritime Economics (IAME).

MASS is likely to penetrate commercial shipping initially through smaller vessels on shorter distances. Ocean-going MASS deployment is likely to take a couple of decades more, and the development of the appropriate regulations, at national and international level, will be one of the major stumbling blocks. To date, only few countries, notably in Europe, have made progress on MASS regulations at the national level. For example, the Norwegian Maritime Authority has already published guidelines for the construction and installation of MASS.[3]

The studies in this MEL special issue on MASS demand a serious rethinking of Levels of Automation (LOA), curricula of Maritime Education and Training (MET), and port-ship interactions. They also offer a comprehensive smart-port architecture, to enable MASS; an assessment framework for cyber security risks; a MASS ecosystem for value creation, and factors enabling the prioritization of MASS adoption. The studies provide detailed insights on ensuring MASS in real-world shipping in the future.

[3] See Circular—Series V, No.: RSV 12-2020, accessed on April 11, 2022 from https://www.sdir.no/contentassets/2b487e1b63cb47d39735953ed492888d/rsv-12-2020-guidance-in-connection-with-the-construction-or-installation-of-automated-functionality.pdf?t=1646784000030.

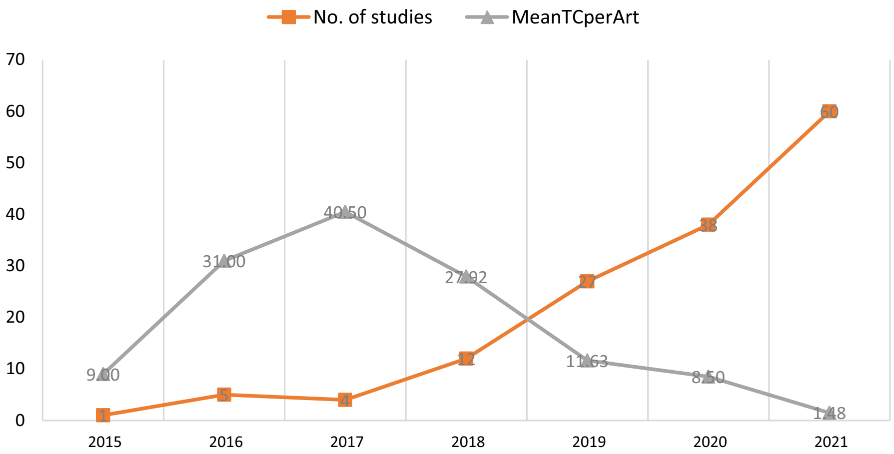

Fig. 1 Publication trend in MASS research

2 Bibliometric review of MASS research

To map recent developments in MASS literature, we carried out a bibliometric analysis of relevant studies published up to December 2021. To identify relevant studies, a systematic literature search was conducted through the Web of Science (WOS) and Scopus databases. In both databases, the final search term, expressed through Boolean keyword search was: “autonomous ship*” OR “unmanned ship*” OR “autonomous vessel*” OR “unmanned vessel*” OR “autonomous surface vehicle” OR “unmanned surface vehicle” OR “autonomous shipping” OR “autonomous surface ship*” OR “unmanned surface ship*”.

The search returned 1006 records in WOS and 3907 in Scopus. After filtering by journal articles only, English language, and relevant subject domains, 279 records from WOS and 389 from Scopus were retained. Following a manual screening of these records, 102 articles from WOS and 99 from Scopus were selected. We removed literature reviews, articles that only briefly mentioned autonomous ships, pure technical studies, and articles that focused on non-merchant aspects of MASS, e.g., costal mapping, offshore wind farm inspection, water quality monitoring etc. In extant literature, technology development studies have received most of the attention, while there is a dearth of studies on MASS from the maritime economics and logistics perspective. This special issue focuses particularly on the latter areas. As several journals are indexed by the two databases, 49 duplicates were removed, leaving us with a sample of 152 studies for bibliometric analysis.

The Bibliometrix package of the R software was used for analysis. The sample of 152 studies were published between 2015 and 2022. They were published in 47 journals and authored by a total of 351 authors. There were 20 single-author documents, with the rest being co-authored studies. Figure 1 depicts the publications trend in MASS research, excluding the pure *technology development* studies. The number of publications has been growing significantly during our sample period,

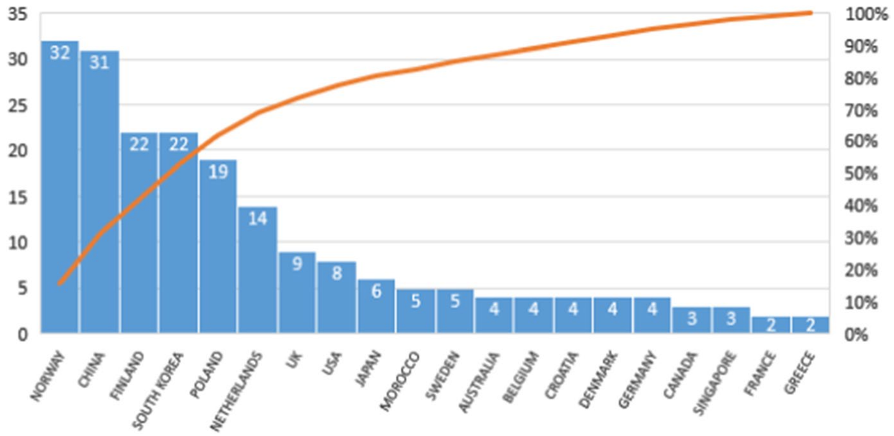

Fig. 2 Countries ranked by number of publications

at an average yearly growth rate of 10.41%. The mean total citations per article (MeanTCperArt) scores are higher in early years, as it usually takes a few years for publications to get attention and be cited. Figure 2 presents the ranking of countries based on number of publications. Norway, China, Finland, South Korea and Poland are the top five. In this special issue, studies are authored by scholars from these countries, represented either by their affiliation or nationality or both.

The bibliometric package allows thematic mapping of topic or field, based on co-occurrence of keyword terms. In this approach, keywords that appear together in different studies are grouped, based on their co-occurrence. Grouped keywords typically represent a theme and they can be grouped in four quadrants based on centrality and density. Basic themes are usually well-developed and can be referred to as the *core* of a topic; motor themes are driving forces of the topic; niche themes indicate isolated topics, and emerging or declining themes are either getting more or less attention in recent time.

Based on Fig. 3, basic themes in MASS literature are mainly shaped around the safety of MASS. The successful adoption and growth of MASS on a larger industrial scale would require maritime safety levels at least at par or higher with conventional ships. Studies related to collision avoidance, situational awareness, and human factors shape the *basic theme*. The *motor themes* include crew reduction, reliability, and energy efficiency dimensions. Reducing operational costs and increasing reliability of shipping services are two major drivers of MASS development. Manning costs are around 40% of total operating costs of a ship, hence, MASS has significant potential for operating costs reduction.

Importantly, the goal of reducing emissions from ships might be achieved to some extent through MASS deployment. Emissions can be reduced by zero emission propulsion MASS (e.g., the battery-powered Yara Birkeland), or switching transport volumes form road to sea through MASS deployment in short-sea-shipping and inland waterways transport.

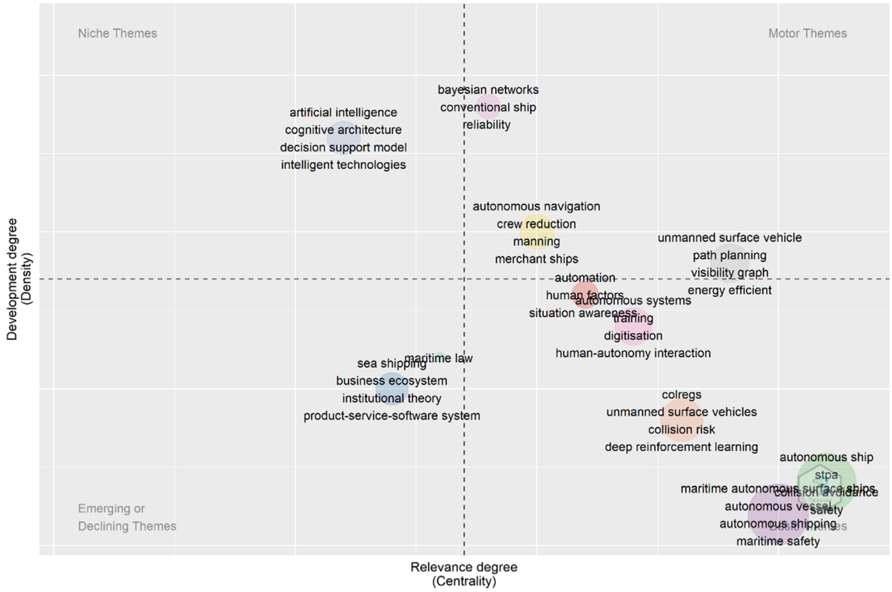

Fig. 3 Thematic map of MASS research

Development of intelligent technologies through artificial intelligence falls under *niche themes*. *Emerging themes* comprise the development of business ecosystems and maritime laws. Studies published in this special issue cover each of the four themes. Poornikoo and Øvergård (2022) and Kurt and Aymelek (2022) deal with basic themes, Boguslawski et al. (2022) with motor themes, Min (2022) and Tusher et al. (2022) with the niche theme, Tsvetkova and Hellstorm (2022) and Li and Yuen (2022) with the emerging themes.

3 Studies in this special issue

Several organizations including IMO, classification societies such as American Bureau of Shipping, Lloyd's register, DNV and others, have produced reports on the classification of the various *levels of autonomy* (LOA) of MASS. The majority of the classifications mainly include four categories, where the lowest level involves ship operations and navigation with human involvement, and the highest level concerns full (unmanned) autonomy. Among the studies in this special issue, Poornikoo and Øvergård (2022) and Kurt and Aymelek (2022) provide detailed reviews of existing classifications of LOA in a MASS context. These two studies also provide a review of the MASS projects, funded by different regional and governmental organizations. Poornikoo and Øvergård (2022) argue that for the LOA of MASS to be useful in practice, they should be classified using a continuous scale rather than discrete ones. Logically, at any given point in time until full autonomy is achieved, the LOA of MASS would be difficult to classify in discrete categories, as there are many systems and sub-systems with many functions which will continue to evolve as autonomous systems over time. Poornikoo and Øvergård (2022) demonstrate the application of their proposed continuous LOA classification through a simulation using fuzzy logic, which could be useful in designing MASS systems.

There have been serious debates on the social impact of MASS development. Many have argued that the commercial deployment of MASS would lead to seafarer unemployment and to an eventual disappearance of the seafaring profession. At present, there are more than 1.6 million seafarers working in international shipping, many coming from emerging economies such as India, Philippines, Poland etc. While in the western world, MASS development projects have been fuelled by a lack of seafarers too, the real impact is likely to be on seafarers from emerging markets. Boguslawski et al. (2022) conducted a large-scale survey of professional maritime students from partner institutions of the International Association of Maritime Universities (IAMU). Their study found that job insecurity is not a real concern among students, which contrasts the on-going debates in the shipping industry. The majority of them believe that new shore-based job prospects will arise with the development of MASS, particularly at the Remote Control Centres (RCCs). However, participants of both Boguslawski et al. (2022) and Kurt and Aymelek (2022) reported that the current Maritime Education and Training (MET) curricula do not as yet cover sufficiently MASS related training and education. According to Boguslawski et al. (2022), maritime students from Northern Europe and South-Eastern Asia have reported comparatively higher relevance of their curriculum to MASS. In Fig. 2, countries from those parts of the world are also leading MASS research in terms of number of publications.

Predictions of possible large-scale adoption of MASS have been scrutinized too. Boguslawski et al. (2022) and Kurt and Aymelek (2022) have asked maritime students and industry experts, respectively, about a possible MASS adoption timeline. Both studies argue that MASS will be successfully implemented by 2040, with smaller scale implementation even as early as 2030. Kurt and Aymelek (2022) have also focused on factors delaying MASS adoption. According to their study, experts believe that technological readiness is not yet at the level needed for the commercial adoption of MASS. While investigating possible impacts of MASS on ports, Kurt and Aymelek (2022) found that MASS navigation when approaching a port is likely to be dangerous, and crew is likely to be still required on a MASS for cargo handling operations. However, MASS has the potential of making port pilotage services smoother. Min (2022), another study in this special issue, outlined the detailed smart port architecture, which can improve MASS-Port interoperability.

Of the various shipping sub-sectors, one may wonder which one is the most appropriate in terms of MASS adoption. Kurt and Aymelek (2022) found that container shipping is the most suitable, followed by dry bulk and ro-ro. Li and Yuen (2022) studied the critical success factors for MASS adoption, considering amongst them technological readiness, environmental fit, organizational resources, and stakeholder readiness. Similar to Kurt and Aymelek (2022), Li and Yuen (2022) also found that technological readiness is the most crucial factor for MASS adoption. Among the technological readiness factors, (i) relative advantage, (ii) compatibility, and (iii) ease of use of the technology were the most important ones. Surprisingly, they found that trialability and observability of the technology are the least important of all the 17 sub-criteria examined in their study. This indicates that the success of MASS mainly depends on what it has to offer to the industry, and its usefulness to the stakeholders.

When a ship approaches coastal waters and heads for berthing, the number of physical objects in its surrounding increases significantly, thus also increasing the possibility of collision. Studies on collision avoidance during MASS manoeuvring have already received great attention by researchers, but port aspects have been greatly overlooked. Min (2022) presents the smart-port development requirements which can be useful in synchronizing MASS-port operations. The smart-port development components can comprise (i) smart infrastructure, (ii) smart traffic flow management, and (iii) smart logistics system design. With the development of these components, a smart port architecture can be designed in a cyber physical space through six modules: (i) digitalization module, (ii) end-point access automation module, (iii) network communication automation module, (iv) security and surveillance module, (v) analytics module, and finally (vi) performance monitoring module.

The MASS operations and management systems will also largely depend on the cyber physical space. Although one of the goals of MASS is to increase reliability of shipping operations and reduce accidents, cyber-attacks on MASS cyber physical space could lead to disasters. Tusher et al. (2022) assessed the cyber security risks of MASS from a systems perspective using a Multi-Criteria Decision-Making (MCDM) framework. The MASS system was thus divided into five sub-systems: (i) navigational system, (ii) propulsion control system, (iii) port operations, (iv) shore or remote-control centres (SCCs or RCCs), and (v) shore-based management offices. The authors found that MASS navigational systems, particularly GNSS and ECDIS, followed by communications devices on RCCs, are the most vulnerable to cyber-attacks. Hence, successful MASS adoption, the authors claim, would need to meet safety standards from both physical and cyber-space technologies.

Finally, the value proposition of MASS is not limited only to reducing crew onboard. In addition to cost reductions, improved safety, and increased revenue potential, MASS can add value to the whole logistics ecosystem. Tsvetkova and Hellstorm (2022) studied the value creation potential of MASS through expert interviews and desktop study of the opinions of innovation leaders. The study found that artificial intelligence (AI) enabled MASS will reduce inefficiency on the overall logistics chain by optimizing not only ship operations, such as route optimization and energy efficiency, but also other inter-related tasks, such as cargohandling operations, hinterland traffic flows etc. However, it should be noted that to achieve such ecosystem-level value, smart-port development (Min 2022) and ensuring cyber-security (Tusher et al. 2022) are prerequisites. As revealed by Li and Yuen (2022), the main driver of MASS for commercial adoption lies on its value to the whole maritime supply chain ecosystem including all stakeholders.

4 Conclusion and future prospects

This special issue advances MASS research on certain, so far overlooked, themes and argues on the merits and demerits from the adoption of MASS in commercial shipping. As data related to actual MASS operations is not available yet, studies in this issue have mainly relied on surveys (Boguslawski et al. 2022; Kurt and Aymelek 2022; Tusher et al. 2022; Li and Yuen 2022), and interviews with maritime industry experts (Tsvetkova and Hellstorm 2022). Two of the studies are purely conceptual (Poornikoo and Øvergård 2022; Min 2022). The studies address several ongoing questions related to MASS adoption, including classification of LOA, MET status-quo, social impact and prospects of maritime employment, intelligent ship-port interfaces, cyber-threats, and finally value creation for all maritime stakeholders.

To advance MASS adoption in merchant shipping, future research on several areas is needed. For instance, the choice of propulsion technology will be crucial. Battery, wind, solar or hybrid energy-based propulsion can make MASS more adaptable in various shipping routes including short- and long range voyages. The possibility of fuel cell-based propulsion, such as hydrogen, should be explored too. In the coming years, further development of niche themes is expected through new AI-based solutions combining big data, blockchain and internet of things (IoT). Such developments will create value through business model transformation in the shipping industry, leading to a *servitization model*. Also new ship financing models are likely to emerge, as the commercialization of MASS gets closer to reality with further development of international regulations and safety guidelines. Finally, MET in countries which supply the world's seafarers need to adapt their curricula by incorporating training for MASS operations through remote control centres.

References

Bogusławski, K., M. Gil, J. Nasur, et al. 2022. Implications of autonomous shipping for maritime education and training: The cadet's perspective. *Maritime Economics & Logistics*. https://doi.org/10.1057/s41278-022-00217-x.

Kurt, I., and M. Aymelek. 2022. Operational and economic advantages of autonomous ships and their perceived impacts on port operations. *Maritime Economics & Logistics*. https://doi.org/10.1057/s41278-022-00213-1.

Li, X., and K.F. Yuen. 2022. Autonomous ships: A study of critical success factors. *Maritime Economics & Logistics*. https://doi.org/10.1057/s41278-022-00212-2.

Min, H. 2022. Developing a smart port architecture and essential elements in the era of Industry 4.0. *Maritime Economics & Logistics*. https://doi.org/10.1057/s41278-022-00211-3.

Poornikoo, M., and K.I. Øvergård. 2022. Levels of automation in maritime autonomous surface ships (MASS): A fuzzy logic approach. *Maritime Economics & Logistics*. https://doi.org/10.1057/s41278-022-00215-z.

Tsvetkova, A., and M. Hellström. 2022. Creating value through autonomous shipping: An ecosystem perspective. *Maritime Economics & Logistics*. https://doi.org/10.1057/s41278-022-00216-y.

Tusher, H.M., Z.H. Munim, T.E. Notteboom, et al. 2022. Cyber security risk assessment in autonomous shipping. *Maritime Economics & Logistics*. https://doi.org/10.1057/s41278-022-00214-0.