Operational and Economic Advantages of Autonomous Ships and their Perceived Impacts on Port Operations

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Abstract Autonomous shipping has been on the agenda of the shipping industry for the last decade and it is now closer to becoming a reality more than ever. Although it is technically possible to automate ships with the developments in autonomous technologies of recent years, the effective use of MASS (Maritime Autonomous Surface Ship) depends on meeting the specific operational needs of shipping. Furthermore, autonomous ships must provide significant economic, environmental, safety and interoperability advantages for a transition to autonomy to be feasible. This study provides a detailed assessment of the operational improvements, possible impacts, and problems that may arise in the shipping industry with the advent of MASS. In addition to this, we assess the processes which would ensure the realization of autonomous ship-port interoperability. In this context, the study discusses the transition to MASS, taking a variety of factors into account, including the acceptability of MASS, benefits and economic impacts of the transition for the shipping industry, the adaptation of vessel types, MASS-port operational interactions (considering various aspects of port operations), and the role of port authorities. Data were collected using a detailed questionnaire, distributed to relevant maritime industry stakeholders. The results of our study highlight the navigational issues facing port areas, and the challenges regarding MASS-port interactions during cargo operations. The findings of this research are expected to assist efforts of successfully implementing autonomous systems in the maritime transport chain.

Keywords: Autonomous shipping; Ship-port interface; Maritime safety; Port operations.

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Introduction

The maritime industry needs to develop strategies that contribute to cost efficiency, competitiveness, safety, and environmental sustainability on a global scale. In response to this requirement, technology has become the mainstay in the design, manufacturing, and retrofitting processes of ships. The use of technology is particularly applied to efficient hull design, engine efficiency, advanced ship-to-shore/ship-to-ship interfaces, and integrated bridge management systems (Jeong and Kim 2013, Im et al. 2018, Lund et al. 2018, Canbulat et al. 2019, Ren et al. 2019). Although technological advancements have contributed to efficiency within the industry, human-intensive operations still create various vulnerabilities in the maritime transport chain. For instance, 70% to 90% of marine accidents are thought to be caused by human error (Porathe et al. 2018). In this regard, the Maritime Autonomous Surface Ship (MASS) promises to reduce these unfortunate statistics.

Fortunately, thanks to advanced sensor and computer technologies, the positive results of autonomous systems in reducing operating costs and crew numbers on-board, as well as increasing navigational safety, show that the transition to MASS is a realistic possibility (Porathe et al. 2014, Wróbel et al. 2017).

MASS is expected to offer a competitive advantage, as it expands the scale and scope of its utilization. However, the initially high capital costs of advanced new technology, and the time it takes for its large-scale implementation pose considerable investment risks (Karlis 2018). It is therefore important the industry as a whole develops strategic planning mechanisms on technology investments, such as MASS, in order to maximise their benefits and hedge related investment risks.

Although advanced technologies make MASS possible, it is a fact that the industry has some concerns. For example, the absence of crew on fully autonomous ships will require the establishment of shore control centres (SCC) and high-quality, reliable shore-ship communication systems which at present come at a high cost (Van Den Boogaard et al. 2016, Ramos et al. 2018). However, it is predicted that there will always be a need for personnel at the SCC for the calibration and maintenance of the autonomous systems on-board, and for analysing the information obtained from MASS (Hogg and Ghosh 2016). Thus, although human error in maritime transport with autonomous ships can be reduced, it cannot be expected to disappear completely. Therefore, some challenges will always exist for the safe operation and monitoring of MASS (Burmeister et al. 2014, Kavallieratos et al. 2018).

Various difficult-to-measure aspects need to be identified and eliminated to enable a smooth transition to MASS in the future. In particular, the uncertainty regarding the benefits and economic gains of MASS are causing hesitation in the investment decisions of ship-owners. Undoubtedly, the operational strategies and practices of shipping companies also need to be reconsidered. For instance, vessel types operating on traffic-intensive routes, or carrying cargo with complex features, or sailing between ports that cannot provide the services required by MASS will affect the decisions of shipping companies concerning the transition to MASS. The interaction of MASS with ports and how to carry out port operations on unmanned-, or reduced-crew ships, is another complex problem. While port automation systems are actively used in cargo handling, transfer, and storage in ports, pilotage services, berthing, and manoeuvring in the port area are still carried out through a human-centred approach (Ghaderi 2020). It can be expected that port operations related to ship arrival/departure may be one of the main technical challenges of ports in servicing MASS, for entrance to the port, manoeuvring, and safely berthing an unmanned MASS in heavy port traffic requires a technically superior technology compared to navigation in open sea.

The limited number of studies on interactions between MASS and maritime supply chains reveals a research gap in the literature. This observation provides an important motivation to researchers, guiding them in shaping their research objectives in this direction. This study (1) reviews the developments in the literature on MASS and analyses possible implications on maritime supply chains; (2) administers a detailed questionnaire to experts working in the maritime transport industry, on the possible impacts of MASS and the problems that may arise from it, regarding maritime transport operations; and finally (3) our study provides a basis for future solutions to MASS-maritime transport operational problems, with the help of our findings.

Trends in Autonomous Shipping

The human-centric nature of maritime transport, and the need to improve on productivity, efficiency, and security, increases the attractiveness of automation, supported by assistive artificial intelligence (AI) and machine learning technologies (Mallam et al. 2020). Experimental and development studies on autonomous commercial shipping have appeared since the early 2000s. The expectations for the future of MASS are expressed by Mikael Mäkinen, President, Marine at Rolls-Royce Plc., as "*autonomous shipping is the future of the maritime industry. As disruptive as the smartphone, the smart ship will revolutionize the landscape of ship design and operations*" (Rolls-Royce Ship Intelligence 2016).

There are actually various levels of autonomy on the path to a fully autonomous ship. At the first stage of autonomy, the crew receives the support of systems and sensors in collecting data or making decisions during ship operations. As an example, a fault is detected and repaired by the crew, following a warning of the machine fault sensor. As the level of autonomy increases, ships are now called *smart ships* or *semi-autonomous ships* (Bureau Veritas 2018). In the next stages of autonomy, ships reach levels whereby they can make decisions and initiate actions under the authorization and supervision of the crew. At the final stages, unmanned, fully autonomous, ships are envisioned. Although different taxonomies are used to describe the degree of autonomy levels (AL) of ships, the latter can be defined in more detail in 6 ranges from low automation (AL1) to the level of totally unmanned ships (AL6). Conventional, manned, ships are denoted as AL0 (Lloyd's Register 2016). Based on autonomy levels, ports are also expected to face some challenges. For example, although it is not necessary to locate SCCs in ports, still the port might be the ideal site and, thus, the premises within it should be identified; in busy ports, this is not always easy (Munim et al. 2021). In addition, with the crew dwindling, a port-based staff may be needed for some tasks such as routine onboard maintenance, or safe-stacking of cargo onboard. These are usually carried out by crew in conventional ships. This could be perceived as another challenge related to crew reduction. When MASS reach a completely unmanned level, the absence of supervision will require uninterrupted and continuous communication among MASS and port and, of course, ensuring this sustainably can be one of the major challenges for ports. The challenges that the described autonomy levels can pose for ports are shown in Figure 1.

Figure 1 Here

Attractive benefits promised of MASS, such as higher safety, monitoring of cargo condition and machinery performance, crew space limitation and increased cargo capacity, and less human error are becoming the subjects of discussion and analysis in recent publications (Kim et al. 2020). In its simplest form, the removal of many facilities and systems utilized for the accommodation and welfare of the crew will create more cargo space and increase the expectation of higher freight income. At the same time, it has been estimated that savings in fuel costs and crew expenditures can result in up to $4.3 million over a 25-year lifecycle, compared to the conventional bulk carrier of the MUNIN project (Kretschmann et al. 2017). MUNIN was the first autonomous ship technology project, developed by a Norway-based initiative, to contribute to the competitiveness and sustainability of the European maritime industry (Rødseth and Burmeister 2012). Information on other projects carried out worldwide is given in Table 1.

Table 1 Here

Project initiatives aiming at the development of MASS have focused on technological research that would enable the transition to unmanned ships. For example, the world's first autonomous and zero-emission container ship (Yara Birkeland-120 TEU) is being built in Romania and outfitted in Norway. The ship is planned to make her maiden voyage by the end of 2021 (Yara 2020, Kongsberg 2021, Beighton 2021). Organizations dealing in the autonomous shipping market are concentrated in the Asia-Pacific and European regions. The global autonomous ship market, which includes these project initiatives, is expected to reach $165 billion by 2030 (Jadhav and Mutreja 2020).

The first generation of autonomous cargo ships developed, such as Yara Birkeland (Yara 2020) and ReVolt (Autonomous Ships HQ 2017) are expected to sail at a lower speed due to safety and technical constraints. The longer voyage times and lower productivity resulting from slower speeds may require more ships to be included in liner shipping itineraries. Rolls Royce envisages that the first stage of ship autonomy will include a remotely operated coastal ship. Then, unmanned ships will likely start locally (such as Yara Birkeland, operated along the Norwegian coast) until international rules and regulations, defining responsibilities, come into force. Finally, it is foreseen that an unmanned ocean-going ship will be in operation by 2035 (Rolls-Royce Ship Intelligence 2016). A timeline for autonomous shipping, as presented by Rolls Royce, is in Figure 2.

Figure 2 Here

MASS-Port Interoperability

Studies examining various aspects of MASS are increasing by the day but, among them, holistic studies that deal with the benefits and economic gains to maritime transport, and the possible impacts of MASS on port operations, are limited. Therefore, this section aims to describe the possible opportunities for ports, in terms of their ability to provide services to MASS, by identifying the difficulties that may be encountered in the interoperability of MASS-port.

Previously published research regarding MASS has generally focused on the technologies needed (Burmeister et al. 2014); and on whether these will be equally as safe as existing ships (Utne et al. 2020); their economic feasibility (Kretschmann et al. 2017); their law and regulatory aspects (Komianos 2018); accident liability (Vojković and Milenković 2020); and resilience to newly emerging risks (Tam and Jones 2018). However, most of the studies on the first phases of MASS introduction were carried out with a focus on the technological developments that will make MASS technically applicable (Rødseth and Burmeister 2012, Porathe et al. 2014). As a result of these studies, several MASS types have already been developed and successfully passed the tests (Kongsberg 2021, Tvete 2013). Subsequent studies have focused on the commercial feasibility of MASS and its economic adaptability to maritime transport chains (Kretschmann et al. 2017).

A systematic literature review by Munim (2019) showed that 90 academic studies have been published on five subjects relating to MASS. These were (1) technological developments-68 studies; (2) innovative applications of MASS-9 studies; (3) safety-5 studies; (4) regulations and management issues-5 studies; and (5) human factor-3 studies. However, MASS-port interactions, and impacts of MASS on port operations have not been considered as one of the research areas.

In the MUNIN project, which is one of the first and most comprehensive projects carried out for the development of MASS, it is envisaged that an unmanned bulk carrier will operate on a slow but long-distance route between two ports (Rødseth and Burmeister 2012). Within the framework of the project, it is stated that a port-based crew will have to board the ship while it is approaching the port area (Kretschmann et al. 2017). In addition, shore and port-assisted services, including SCC, and the support of a maintenance team during the stay at the port are envisaged. The transfer of crew for pilotage, maintenance, and cargo-related tasks (cleaning of holds and stability of cargo) would require a helicopter and a landing area, transfer boat, or a pilot launch capable of providing remote pilotage. These can be considered as the main impacts of MASS on port operations.

Hogg and Ghosh (2016) conducted an examination on the factors impacting the effective operation of unmanned commercial ships in the maritime transport chain. As with the MUNIN project, Hogg and Ghosh (2016) shared similar views on boarding the ship at the port, regarding maintenance and cleaning of cargo holds. The authors also predicted that as ship designs become more complex and produce big data, new roles that might affect port operations may emerge. This means that for ports that do not invest in the necessary facilities and personnel, or cannot keep up with the times, the transition to autonomy will be problematic.

In their study in which they examine the impacts of autonomous shipping on regulations, technologies and industries, Kim et al. (2020) state that the effective and efficient operation of MASS depends on healthy communication and cooperation between the shipping company and the port. They note that autonomous ports could eventually be developed to support unmanned ship operations. The autonomous ship YARA Birkeland, developed by Kongsberg, will be able to automatically perform mooring, berthing and departure operations without a specialized quay, or extra port facilities for MASS (Yara 2020). Komianos (2018) predicted that the innovations and regulations introduced in the autonomous shipping era could impact not only MASS, but the entire maritime transport industry, with developments in operational, legislation and quality.

On the other hand, the introduction of new laws is also necessary to determine liabilities if something goes wrong in autonomous shipping.. IMO (2017)'s Regulatory Scoping Exercise (RSE) initiative for the safe, secure and environmentally efficient adaptation of MASS is expected to come into effect in many areas including ports. In the study of Ringbom (2019), in which the possible regulations regarding autonomous ships were analysed, it was stated that if MASS were legally accepted, based on the ship definition in United Nations Convention on the Law of the Sea (UNCLOS), the existing rights and obligations of the flag, coastal and port state could be equally valid.

From the studies so far, it can be inferred that the major technical difficulties which can be faced by ports in serving MASS are safe navigation, berthing and manoeuvring. Advanced coastal information and communication technologies (ICT) systems that can provide remote pilotage services are expected to play a critical role, if the team that will take control of MASS-port operations, as expressed in projects like MUNIN, is to be eliminated.

Consequently, a number of activities, previously performed by the crew, must be undertaken by port-based staff. These activities can be divided into three categories; (1) ship operational management, (2) ship technical management, and (3) cargo operations management. Ship management activities include operationally safe navigation, berthing and manoeuvring operations and technical maintenance and repair operations. The activities of cargo operations management include cargo handling such as cleaning of hatches, stability assessment, stacking etc. Thus, while MASS may offer a simplified ship design and reduction in human-centred tasks, it is a fact that a port-based crew will still be required.

Methodology

4.1 Questionnaire objectives

The objective of the questionnaire was to access the opinions and knowledge of experts on the possible effects of autonomous ships on port operations in general. The target group were experts in the area of ship-port operations. To reach a sufficient number of participants, the International Association of Ports and Harbours (IAPH), the International Chamber of Shipping (ICS), the Port Operators Association of Turkey (Turklim), the Turkish Ship-owners Association (TSA) and major ports in the world were contacted, with the request to distribute the questionnaire to their members, stakeholders and employees. In addition, a line of communication was created via the maritime universities' alumni associations, with the same request. Since the participants were working in a wide range of institutions, organizations, and companies, with a wide spectrum of job titles, we employed the "wisdom of the crowd" approach to form the best overall decision by combining the answers from different perspectives rather than relying on individual views. In other words, the views of the sample group evaluated the transition to autonomy from the perspectives of ship-owners, ports, shipbuilders, and academics. Since there was no feedback on how many people the questionnaire was delivered to, information about the response rate is not available.

4.2 Questionnaire design

Participants first came across a login screen with information about the purpose for which the questionnaire was created; why it was important; and how long its completion would take. Next, a pledge was given that personal information would not be shared with third parties and that the answers would remain anonymous. Participants who accepted these conditions were able to continue to the questionnaire; for those who did not, the questionnaire was terminated.

The questionnaire consisted of two parts. The first, included questions meant to evaluate the general perspective of the participant about the transition to MASS, in accordance with the aims of the research. The second part consisted of questions meant provide information, based on the experiences of the participants, about the introduction of MASS and its possible effect on port operations. The structure of the questionnaire consisted of 8 question sets. These were:

1. Participant profile
2. The necessity of transition from conventional ships to autonomous ones
3. The possible benefits of the transition
4. The economic impacts of the transition
5. Adaptation of cargo ships to autonomy
6. The possible impacts of autonomous ships on port operations
7. The possible problems of autonomous ships on port operations
8. The role of the port authority/operator

In order to analyse the answers consistently, various answer methods were considered and utilised. For the first set of questions, multiple-choice and open-ended answering methods were chosen. For the remaining 7 question sets, the five-category Likert scale was adopted. However, for the 2nd, 4th, 6th, 7th, and 8th set of questions, in addition to the Likert scale, an answering tab was included where the participants could write down and submit additional comments and opinions. The questionnaire was created through *Google Forms* and was then distributed to the participants through an online link provided by the application; it was distributed between March 1, 2021 and March 31, 2021. A total of 54 responses were received.

4.3 Data analysis

The statistical analysis of the data obtained from the questionnaire was carried out in SPSS, and the final versions of the graphs presented below were produced with the help of Microsoft Excel. A (1) to (5) Likert scale was used twice, as described in Table 2. Grammar and syntax of open questions was improved when necessary; their answers, which are thought to contribute to the study, have been used in appropriate places in the results and discussion sections.

Table 2 here

Profile of Participants

In the first part of the questionnaire, details about gender, profession, and work experience, which were thought to reflect the views of the participants, were asked. A total of 54 people participated in the questionnaire, 46 of whom stated that they were male and 5 females. Three participants preferred not to indicate gender. Also, the participants practiced their professions in a range of countries, thus covering the global maritime community, and a range of cultural and geographical differences. The participants were asked to provide information about their current job and work experience. As a result of the answers obtained. Job titles and work experience are presented in detail in Table 3.

Table 3 here

As seen in Table 3, the first three occupational groups consisted of research institutions/academia (46%)[1], port authority/operators (20%), and ship-owners/operators (17%). The results also show that more than 81% of the participants have had more than 5 years' work experience in the maritime sector. Since the number of participants in occupational groups was relatively small, it was not possible to

[1]Since the integration of autonomous systems is a new topic in the field of maritime transport, the R&D process has not been completed yet. Therefore, the participation of research institutes and academics in the survey was much higher than other occupational groups. In addition, research institutes include employees of marine technology and the R&D departments of ports.

provide parametric test assumptions. For this reason, non-parametric Kruskal-Wallis Analysis of Variance was applied.

Table 4 here

The Asymptotic Significance (Asymp. Sig) of Kruskal Wallis was found equal to 0.207 > 0.05. This means that there was no significant difference between the means of the occupational groups, at the 5 percent level of significance. The groups were, thus, equivalent to each other.

The distribution of the sample was considered as quite good: in particular, responses from both academia and industry, on a subject such as autonomous shipping, which is at the R&D stage, are equally useful for analysing the opinions of experts with different perspectives.

Results

6.1 Transition from conventional ships to MASS

It is obvious that the transition to MASS can be realized much more easily with reliable knowledge transfer and sustainable cooperation between industry, academia, and R&D (See Quote 1 and Quote 2). Therefore, the industry's views are critical in determining the improvement and development processes in the transition to MASS. In order to evaluate the current expectations of the sector regarding the transition to MASS, the participants in the sector were asked (1) whether the transition to MASS is a need, (2) the adequacy of existing technologies, and (3) the adequacy of existing academic studies. Thanks to the feedbacks received from the industry, the development of existing technology and the shaping of the ongoing research in accordance with the expectations of the sector can be ensured. At the same time, opinions on whether the transition to MASS is seen as a need by the sector can be expected to contribute to clarifying the speed and direction of actions to be taken.

Quote 1 Here

Quote 2 Here

Figure 3 presents the answers of the participants to the questions on the transition from conventional ships to MASS. While more than half of the participants considered that the transition is needed, 13% stated that there is no need. Only one of the participants stated that it is not absolutely a need, by answering "strongly disagree". As regards the occupational groups, 66% of the participants from "others", including respondents working as logistics service providers, seafarers, designers/builders, or members of maritime institutions, adopted the view that the transition to MASS is a need. This is followed by academicians and port authority/operators, stating that there is a need for the transition to MASS, at a rate of 56% and 54%, respectively. The lowest rate was obtained from the ship owner/operator occupational group, with 44%. However, this group had stated that "the transition to MASS is definitely a need" at the highest rate, by answering "strongly agree" with 33%.

Figure 3 Here

Looking at the profile of the participants in terms of experience, job titles, and geographic location, it can be said that their answers reflect the views of the industry in general and that the opinion that "the transition to MASS is a need" is prevalent in the maritime sector. As such, the motivation of the sector is expected to be high in the development of MASS, ports, and ship-port interaction, which are vital for the spread of autonomous shipping.

Figure 3 also includes the opinions of the participants on the adequacy of the existing technology for the transition to MASS. According to the results, 46% of the participants considered the current technologies insufficient. 13% of the participants expressly denied the adequacy of existing technologies by giving a "strongly disagree" response. Among the occupational groups, academicians were the greatest group (with 56%) who found current technologies insufficient. In addition, approximately 26% of the participants remained neutral in this regard. On the other hand, 28% of the participants found the existing technologies sufficient for the transition to MASS, while only 5.6% (3 participants) accepted the adequacy of the technologies without any doubt. According to the Likert scale, with a mean value of 2.74, the general opinion of the sample group focused on the insufficiency of existing technologies. The level of current technologies forms the basis on which autonomous shipping will be built. Therefore, these results clearly show that technologies need to be developed to accelerate the transition to MASS.

As regards the adequacy of academic studies on the transition to MASS, approximately 54% of the participants stated that they believe academic studies are inadequate. It is difficult to talk about a group that stands out with different views among occupational groups, because the percentage of participants who found academic studies sufficient was only 17%. This figure corresponds to 1 or 2 people in each occupation group. The Likert scale mean value was 2.52.

In this case, the question of "how is the transition to autonomous shipping possible under current conditions?" comes to mind. While the transition to MASS is currently seen as a need, firstly the competence and number of academic studies should be increased and the technologies required for the transition should be improved and developed to cope with challenges such as safety, operational, regulations, MASS-port interface, etc.

6.2 Possible benefits and economic impacts of the transition to MASS

In this section, the participants were asked about the possible benefits that can be obtained in the case of transition to MASS. The benefits were classified under 5 headings. These are (1) operating cost reduction (fuel consumption, crew cost etc.); (2) port cost reduction (port dues, handling fee, other port service fees, etc.); (3) increase in navigational safety; (4) increase in social opportunity in terms of on-shore jobs and better working conditions; and (5) reduced impact of unexpected disruptions (wars, piracy, crisis, pandemics, etc.).

Participants were asked to express their opinion about the probability of realizing the possible benefits of MASS. Figure 4 presents the answers given to these questions. The majority of the participants see it likely that MASS can provide a reduction in operating costs, port costs, impacts of unexpected disruptions, and an increase in navigational safety. On the other hand, the increase in social opportunities was not considered likely by the participants.

The reduction in operating costs was seen more likely by the participants than other possible benefits of MASS, with a mean value of 3.76. This is followed by the other possible benefits of MASS which are an increase in navigational safety, reduced impacts of disruptions, and port cost reductions, with mean values of 3.43, 3.11, and 3.07 respectively. Here, the answers to the question about the increase in social opportunity, in terms of on-shore jobs and better working conditions, differed from other possible benefits of MASS. There is a general belief that social opportunities will not increase, with an average value of 2.87. It can be deduced from this that as a result of the transition to MASS, crew currently on-board will seek jobs ashore, but according to the opinions of participants, job opportunities ashore will not increase, so there will probably be an increase in unemployment.

Figure 4 Here

As the second part of this section, the participants were also asked about the likely realization of the identified possible economic impacts from the transition to MASS. These have been defined as follows: (1) income increase, (2) profit increase, (3) decrease in the number of employees, (4) easier access to funding sources, and (5) coping with the impacts of an economic crisis more easily. Figure 5 shows the responses. An increase in income and profit is expected from the transition to MASS. At the same time, more than 70% of the participants see a likely reduction in the number of on-board crew, and therefore, a decrease in crew costs is also predicted.

Figure 5 Here

It can be said that the transition to MASS could whet the appetite of financiers: 31% of the participants considered that reaching funding resources will be easier with MASS. This could mean that, according to the opinions of the participants, the financial risks of investing in MASS would be seen acceptable by entrepreneurs and financial institutions. In addition, although the participants thought that MASS would have a positive effect on dealing with economic crises, a high proportion of the participants (48%) could not fully predict what effect MASS would have in this regard.

Due to the answer collection method used in the questionnaire, it was not possible to reach a conclusion about the numerical value of the economic benefit, envisaged to be obtained. When the opinions of the participants in Figure 4 and Figure 5 are compared, it can be said that a cumulative benefit, achieved by both cost reduction and income increase, forms the basis of the view that profits and income are likely to increase.

6.3 Adaptation of cargo vessel to autonomous systems

In this section, the views of the participants about the type of ship better suited for autonomous systems were consulted. These were (1) dry bulk carriers, (2) tankers, (3) containerships, (4) Ro-Ro vessels and (5) LNG carriers. Depending on the ship type, it was also asked the extent to which cargo handling operations at ports could be carried out in harmony with the use of autonomous systems. Information on ship dimensions, technical and operational features, route, and the cargo characteristics of the five ships were not provided to the interviewees.

In Figure 6 presents the results obtained on the compatibility of autonomous systems with ship operations and port services. From the box and whisker plot in Figure 6, the range in which most of the answers are clustered and the mean value of all responses can be seen. A general indication emerges that containerships and their cargoes can be operated in a more compatible manner with autonomous systems compared to other ship and cargo types. It can be said that containerships can be more easily adapted to robotized systems, due to the standardization of operating conditions offered by containerization, which makes them more compatible with autonomous systems.

Figure 6 Here

The results obtained for other ship types appeared to be similar to each other. Among them, dry bulk carriers and Ro-Ro ships stand out with a notch, but when the averages are compared with the Kruskal Wallis test, it appears that there is no significant difference in the values obtained compared to the other two ship types, tankers and LNG carriers.

6.4 Possible impacts and problems in port operations of MASS

In this section, the possible impact of MASS on port operations and possible problems that may be encountered during such operations are discussed. The described possible impacts and possible problems are shown in Table 4.

Feedback was obtained from the participants using the Likert scale on the identified impacts and problems. The answers of the participants are shown in Figure 7. The possible impacts and problems are numbered as in Table 4; answers are numbered in Figure 8.

Table 4 Here

Figure 7 Here

As a result of the answers obtained on the possible impacts of MASS on port operations, mean values were calculated in order to reveal the general opinion of the participants. These mean values are illustrated in Figure 8.

Figure 8 Here

The mean values show that all possible impacts of MASS on port operations are considered likely to occur. Among them, the possible impact, described as "Crew is required aboard the vessel for cargo handling preparations (Unlashing / lashing, opening hatch covers, loading / unloading equipment readiness, etc.)" has had the highest mean value of 3.63. Less than 15% of the participants argued that no personel is required aboard to prepare the cargo and the vessel for handling operations. 24% of the participants were undecided about this impact of MASS. This view actually overlaps with the labour-dependent situation of today's shipping. In other words, from the perspective of stakeholders, it is believed that no matter how much the current shipping system is supported by autonomous systems, autonomous ships will still need external manpower.

Another possible impact, which seems to be highly probable, is that MASS will facilitate port pilotage services. About 60% of the participants agreed on this, with a mean value of 3.52. Another possible impact of MASS on port operations, which more than half of the participants agreed upon, was improvements in cargohandling efficiency. Although only 18% of the participants expressed an opposing opinion on this impact of MASS, the calculated mean value was 3.41. Less than 50% of the participants agreed with the other identified possible impacts of MASS on port operations. Accordingly, the mean values of the possible impacts of MASS defined as "berthing and mooring operations become easier"; "increase in shore crew needed for cargohandling services"; and finally "documentation related to cargo becomes easier", were calculated as 3.37, 3.35 and 3.19 respectively.

As a result of the answers, it can be concluded that operations such as manoeuvring in the port area, berthing and mooring, are expected to be easier with MASS. In addition, it is expected that crew will board for cargo handling preparation, and an increase in the number of personnel at ports for cargo handling services. Nevertheless, it can be said that the reason behind predicting an increase in cargo handling efficiency is that the documentation procedures related to cargo will become easier.

As a second part of this section, the mean values of the identified problems that may be encountered during the port operations of MASS are illustrated in Figure 9. For all identified situations, the general opinion of the participants was that these problems are likely to occur.

Figure 9 Here

Among the possible problems, approximately 57% of the participants found likely the realization of the problem defined as "autonomous navigation in the port area (e.g., w.r.t. collision avoidance)". The mean value for this problem was 3.57. Based on the received answers, 50% of the participants thought that the situation defined as "remote control access to cargo handling operations" would materialize. Similarly, 48% of the participants agreed that the issue of "ship-port communications" will be one of the major problems to be experienced. Their mean values were obtained as 3.44 and 3.37, respectively.

Participants agreed on the emergence of two more possible problems, being "inadequacy of shore crew regarding the type of the cargo handled" and "testing, verification, and validation of characteristics such as quality, quantity, and type of cargo handled", with the rate of 33.3% and 43.4%, respectively. However, since 30% of the participants did not see likely the emergence of a problem regarding testing, verification, and validation of cargo characteristics (such as quality, quantity, and cargo type), the mean value was calculated as 3.15 and this problem was stated as the least likely to occur.

Discussion

With the inclusion of MASS in the maritime transport chain, shipping operations are expected to face emerging challenges, mostly in terms of ship and port productivity. Concerns do exist, however, regarding MASS time in port, related to a series of maintenance and cargo preparation challenges, which were previously carried out at sea. According to Kretschmann et al. (2017), these will now be carried out by shore staff. Sceptical voices also point out that, in connection with the increase in the operations to be carried out in port, an increase in berth occupancy and higher density of port traffic is predicted, and hence the performance and productivity of both the port and the shipping company may decrease. Ghaderi (2020) points out that the transition to unmanned MASS may not attract the interest of many ship-owners, or seaports, due to such possibilities. Although the projects carried out on MASS reveal advantages in security and other benefits, the fact that operational performance and sustainability might be affected due to such possible problems, raises concerns among maritime transport stakeholders.

On the other hand, the opportunities created by the transition to MASS for ports are not forsaken. Briefly, these comprise increased short-sea shipping activity in inland and territorial waters; remunerative port dues; shore (port) employment; cargo handling operations and commercial regulations (Ghaderi 2020). Moreover, thanks to the advanced automation and communication technologies, ports could be placed in a more critical position, in monitoring and controlling local and international supply chains.

The extended discussions on the open-ended answers given in the questionnaire by participants show that the development strategies of shipping companies and the role of port authorities in the transition to autonomy will be valuable. According to some comments, it might be technically difficult for MASS to achieve full autonomy during port operations (see quote 3). There is also another view according to which port performance will not be affected by the autonomy of the ship (see quote 4). This argument here is that the responsibility for the work to be done after berthing belongs to the stevedore. However, since the preparation tasks of the autonomous ship for its next voyage will be carried out by the shore personnel, port time and, therefore, port performance, would be affected.

Quote 3 Here

Quote 4 Here

One concern was that high-risk cargo and passenger transport cannot be done by autonomous ships (quote 5), and cyber-security will be a major technical challenge (quote 6). In the projects carried out so far, high-risk cargo and passenger ships have not been considered. It is indeed imperative that MASS prove themselves in this regard and more research should be carried out. One participant (a port authority/operator with more than 10-years of experience) singled out Ro-Ro and coaster ships as the most suitable ones for MASS-port interoperability. The same respondent considered offshore ships used for surveys and inspections as the first type of ships suitable for the transition to autonomy. Another participant stated that emergency response and related communications can be one of the important problems when MASS is faced with unexpected situations during voyage and outside port areas.

Quote 5 Here

Quote 6 Here

Some of the comments on the role of the port authority in autonomous transport were on port investments (quote 7); port competition (quote 8); adapting port infrastructure to MASS (quote 9); and the security of port operations (quote 10) within the framework of autonomous ships. Based on these comments, uncertainties related to the impacts of MASS on port operations are mainly seen as high capital requirements for technological investments; safety enhancements; competitive advantages; and contribution of autonomous shipping to the overall sustainability of the maritime transport chain. These views also point out not only the uncertainties but also a strong need for the maturity of technological innovations, economic and operational feasibilities, and more research efforts on the issue.

Quote 7 Here

Quote 8 Here

Quote 9 Here

Quote 10 Here

Conclusions

During the last decade, the shipping industry has joined the digital transformation trend following aviation and other transport modes. Thanks to technological advances in the fields of sensors, computers and data processing, the idea of Maritime Autonomous Surface Ship (MASS) ceased to be a concept and came closer to reality. New ideas have emerged in many areas of MASS, such as designs, economic feasibility studies, adaptation to existing transport networks, regulations and various other challenges.

The benefits of the transition to autonomous ships vary, and the opportunities that the shipping industry could enjoy from this transition are enormous. Basically, reduction in ship operating costs and increase in navigational safety are the most obvious benefits. The economic and financial benefits suggested by current studies are mainly for shipping companies. In this context, MASS is expected to provide a significant increase in productivity in ocean shipping. MASS will also have important impacts on other components of the shipping supply chain, i.e., ports, shipyards, regulators, etc. In the near future, the improvements achieved through MASS should be followed up and examined in detail. Although the benefits of autonomous ships are obvious to most, the development of MASS technology needs to prove itself against the challenges and difficulties it will undoubtedly encounter.

The main purpose of this study was to analyse the industry's approach to MASS and the perceived impacts of MASS on port operations. Among others, we attempted to determine whether MASS is seen as a necessity by the industry. We solicited the opinions of industry experts on current and future technologies and the need for more research. The paper also looked into the industry’s transition to MASS with regard to economic benefits, and the adaptation of cargo vessels to autonomous systems.

The two most important findings of the study regard the problems that will be encountered with autonomous navigation in the port area, and the impacts concerning the crew required on-board for cargo handling preparations. Our findings complement those of earlier studies. However, this study appears to be the first one to clarify the expected impacts of MASS on the maritime transport chain and in particular on port operations, based on the opinions of experienced stakeholders. A limitation of this study concerns the current technological challenges and the various perceptions on MASS of the various individual stakeholders. In spite of these, the study certainly adds to our understanding of the transition to MASS in maritime transport chain and the likely problems that port operators could face. Further research might explore the best shipping and port adaptation practices, with the lowest possible cost. Further studies could also be conducted to determine the effectiveness of port operations serving different MASS based on their cargo specialisation.

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Figures

Autonomy Level	Description	Challenge for ports
AL0-Human only	No autonomous function.	No extra challenge
AL1-Low automation	On-ship decision support	No extra challenge
AL2-Partial automation	On and off ship decision support	No extra challenge
AL3-Conditional automation	Active human in the loop	SCC and port-based maintenance crew
AL4-High automation	Human on the loop - operator/supervisory	AL3 plus cargo related support
AL5-Full automation	Rarely supervision	AL4 plus pilotage and berthing
AL6-Unmanned	Unsupervised operations	AL5 plus seamless communication

Figure 1. Autonomy Levels (AL) of ships
Source: Based on Lloyd's Register (2016) and Rødseth (2019)

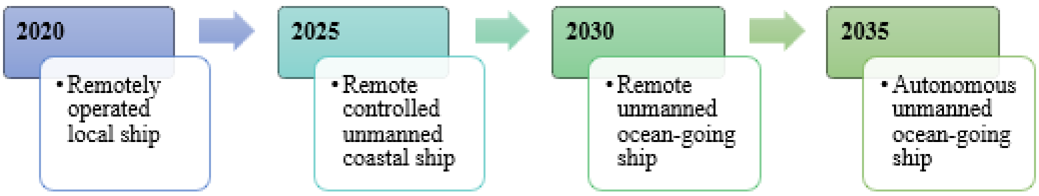

Figure 2. Timeline for autonomous shipping
Source: Rolls-Royce Ship Intelligence (2016)

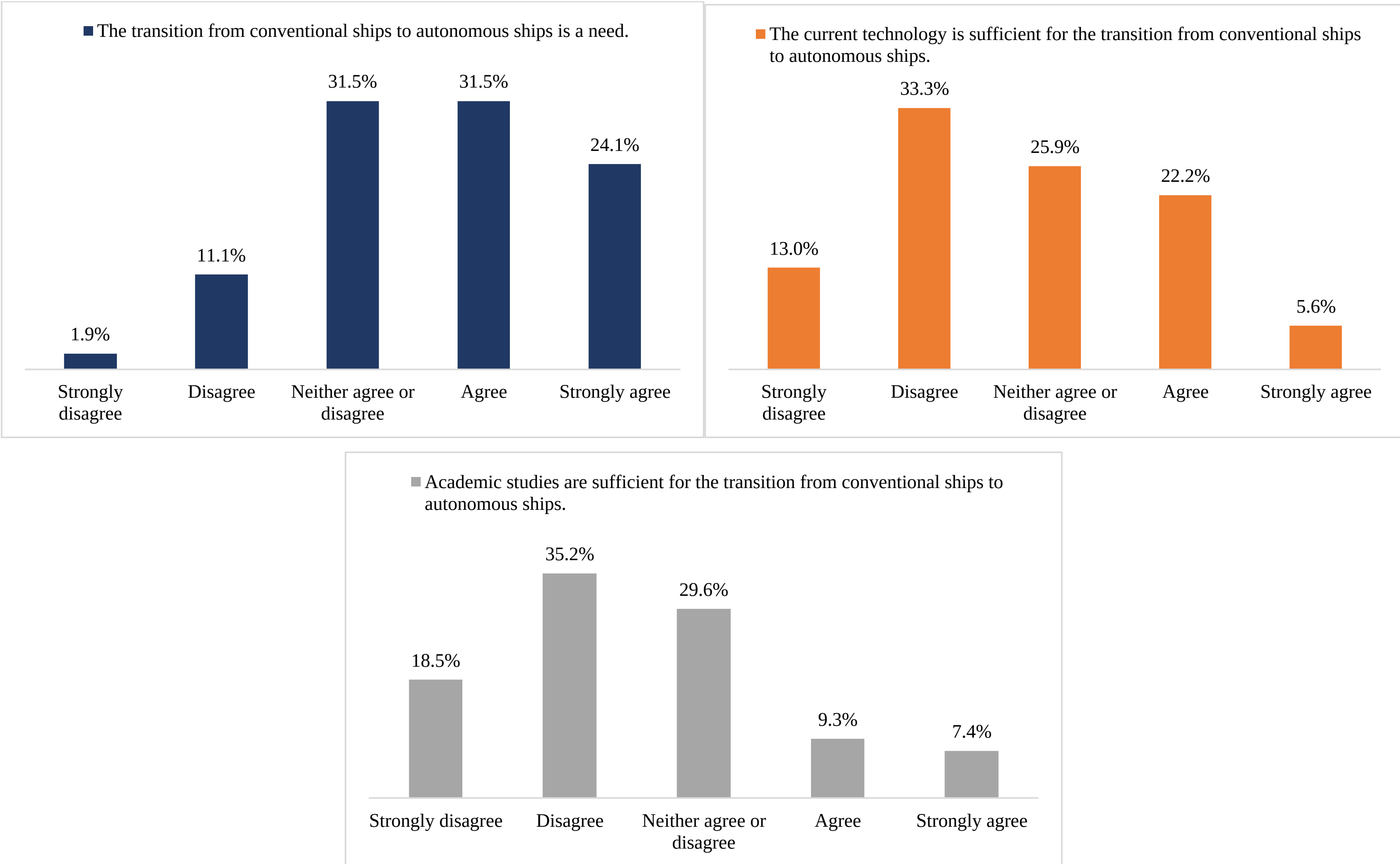

Figure 3. Questionnaire answers about the necessity of transition to MASS, sufficiency of current technology and academic studies

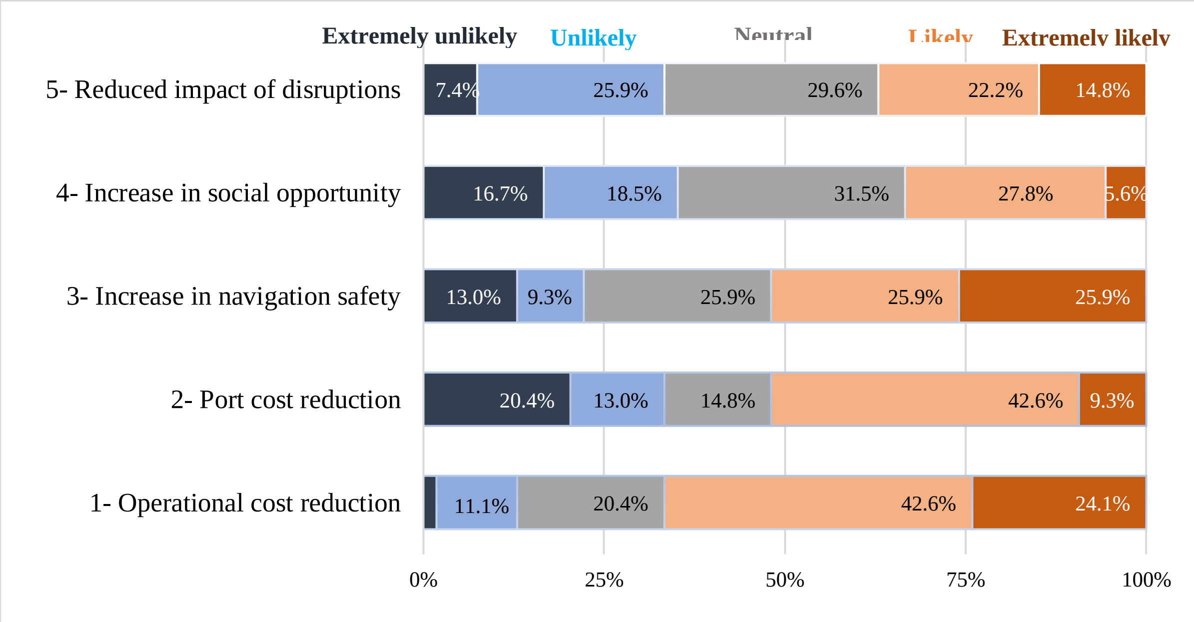

Figure 4. The possible benefits of the transition to MASS (N=54)

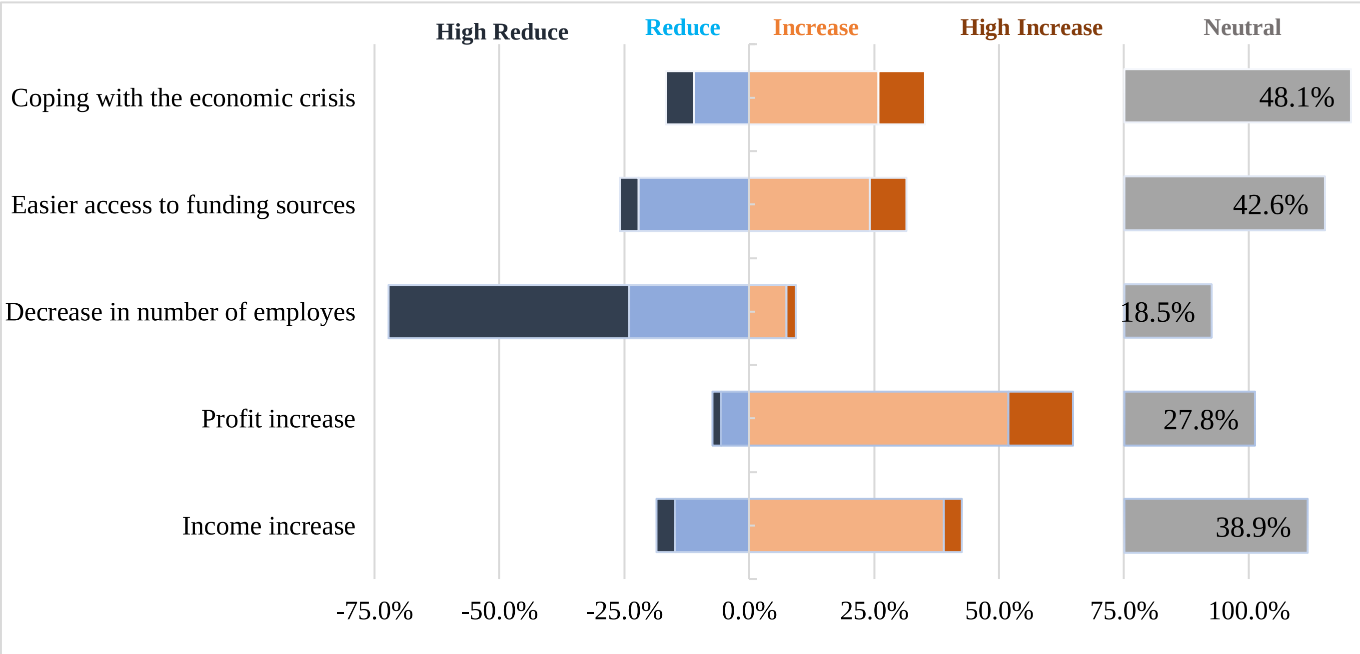

Figure 5. The possible economic impacts of the transition to MASS (N=54)

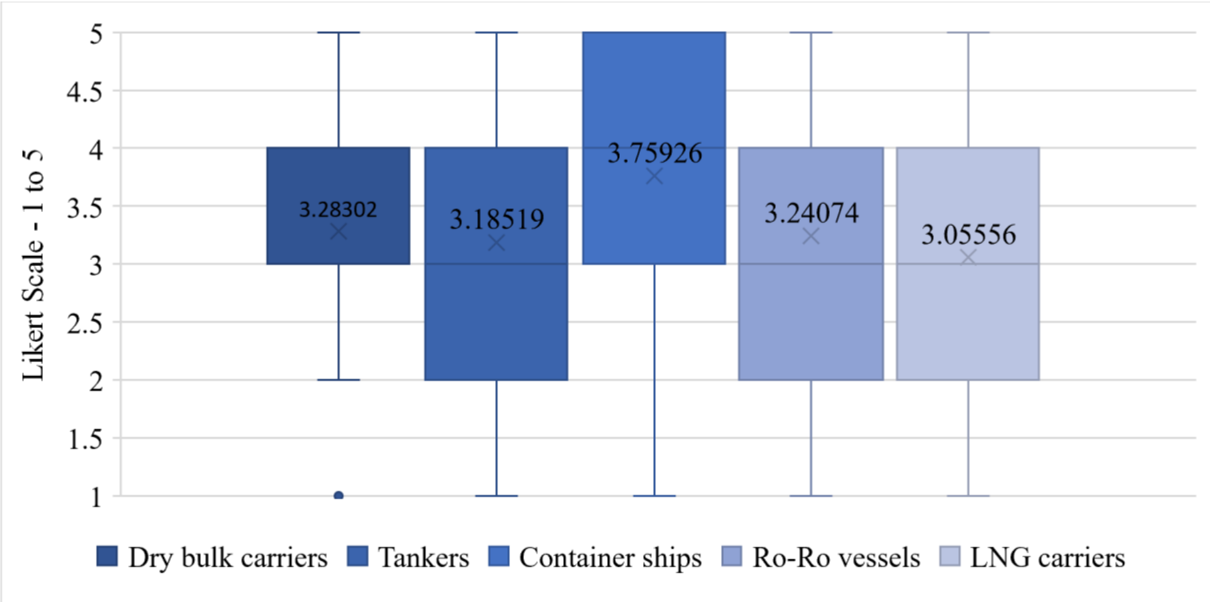

Figure 6. Adaptation of cargo vessels to autonomous systems (N=54)

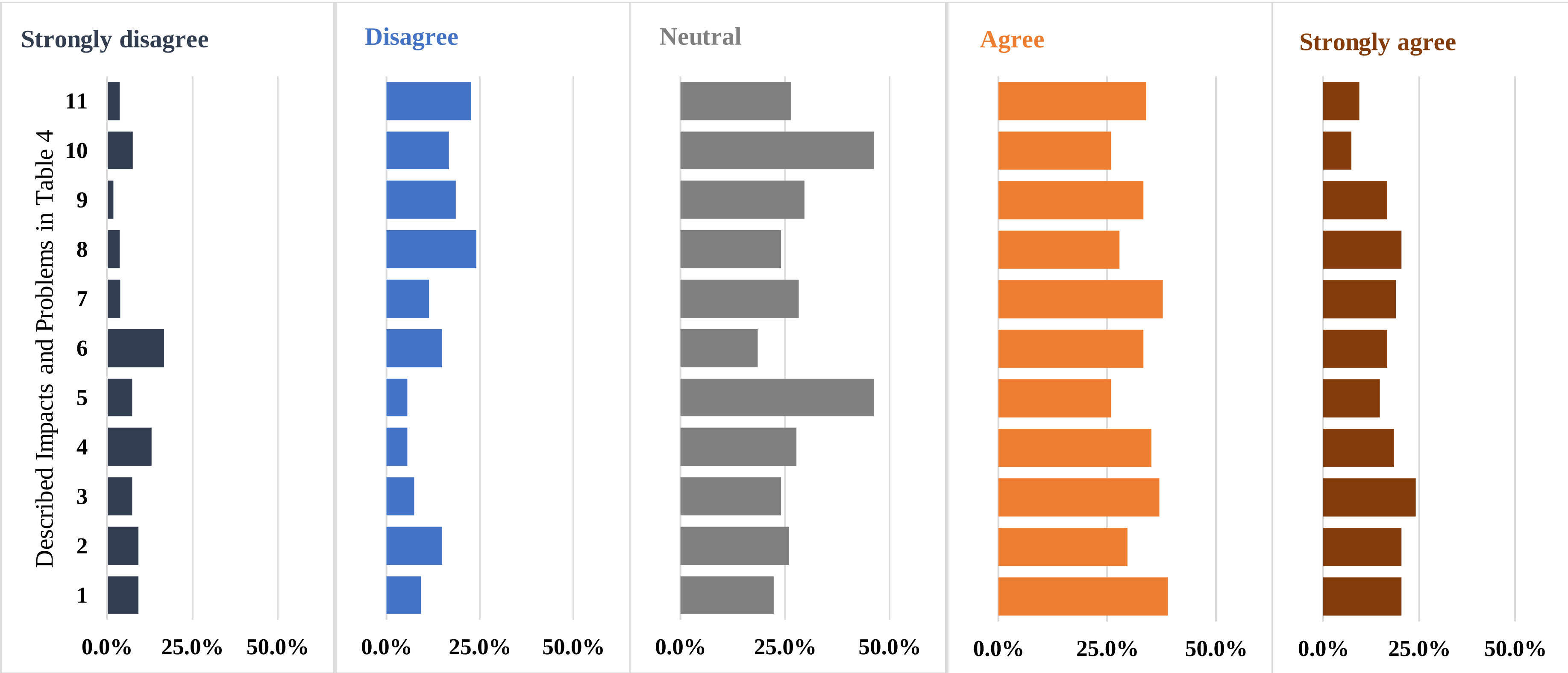

Figure 7. MASS' possible impacts on ports and possible problems in port operations (N=54)

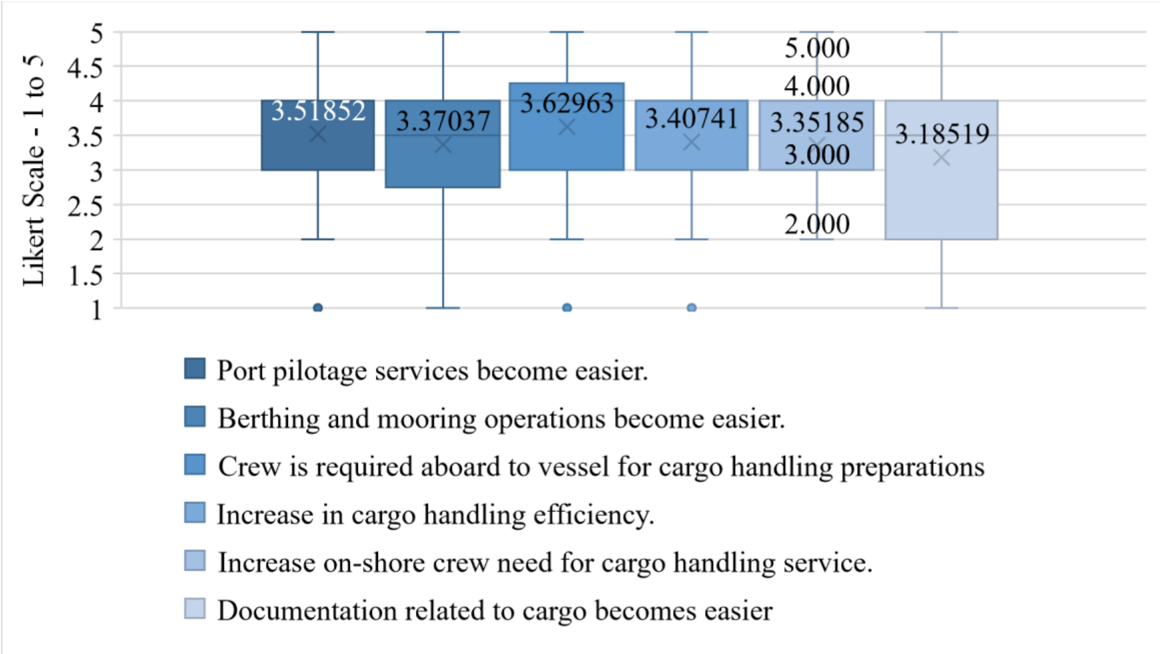

Figure 8. Mean values of possible impacts of MASS on port operations

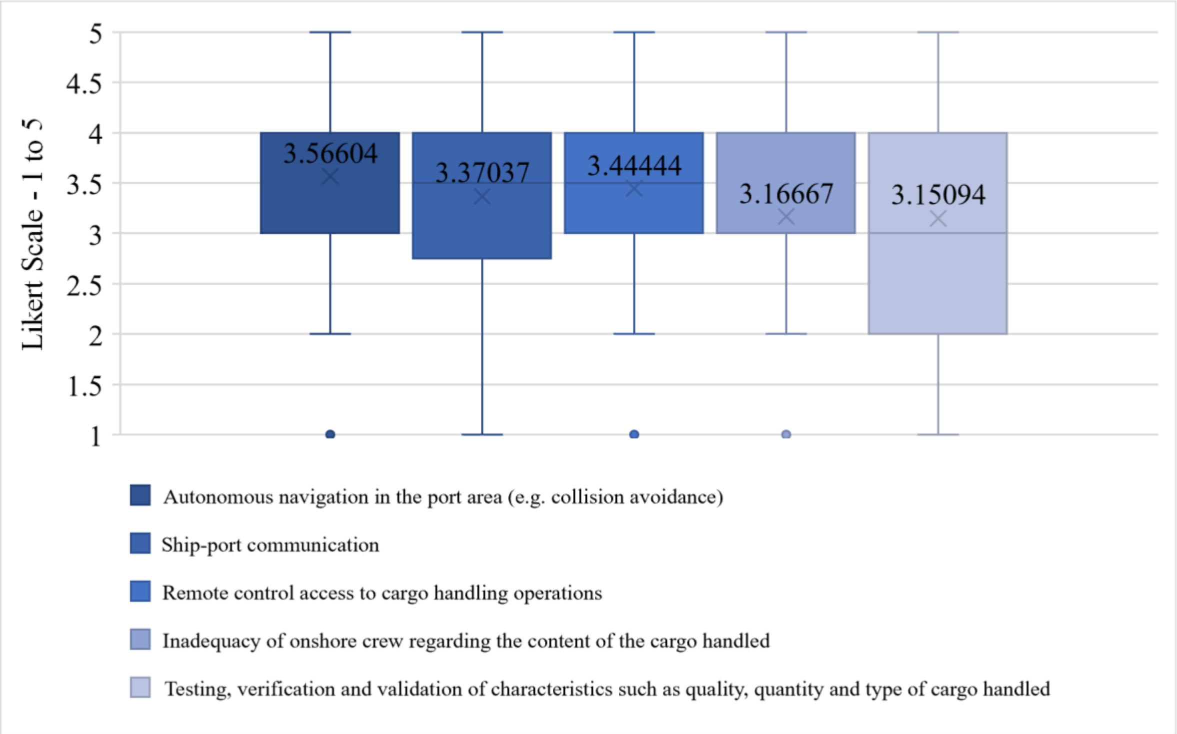

Figure 9. Mean values of the possible problems in port operations of MASS

Tables

Table 1. Major projects related to autonomous shipping

Project	**Type**	**Country**	**Organization**	**Source**
MUNIN	Autonomous Ship Development Program	European Countries	Fraunhofer, Marintek, aptomar, Chalmers, Hochschule Wismar, Marine Soft, Marorka, and UCC	Rødseth and Burmeister (2012)
ReVolt	Unmanned, zero emission, shortsea container vessel	Norway	DNV GL, Transnova, NTNU	(Tvete 2013)
AAWA	Remote and autonomous ships	Finland	Tampere University of Technology, VTT Technical Research Centre of Finland Ltd., Abo Akademi University, Aalto University, the University of Turku, Rolls-Royce, DNV GL, Inmarsat, Deltamarin, NAPA, Brighthouse Intelligence, Finferries and ESL Shipping.	Jokioinen (2016)
YARA Birkeland	Autonomous and zero emission container vessel	Norway	Yara and Kongsberg	Yara (2020)
UCSDA	Unmanned cargo vessel	China	HNA, CSS, ABS, DNV GL, Chinese Ship and Marine Engineering Design Institute, and Shanghai Marine Diesel Engine Research Institute	Offshore Energy (2017)
ISHIN Next	Autonomous ferry	Japan	Mitsui O.S.K. Lines, Ltd., Ferry Sunflower Co., and Rolls-Royce	MOL (2018)
Autoship	Autonomous shipping initiative	Italy, Norway, Scotland, Belgium and France	Ciaotech S.r.l.-PNO Group, Kongsberg, Sintef Ocean AS, University of Strathclyde, Eidsvaag AS, Blue Line Logistics NV, Bureau Veritas, De Vlaamse Waterweg NV, and EU	AUTOSHIP (2020)
MOSES	Automated dock, vessel and handling system	Greece, Cyprus, Spain, Italy, Netherlands, Denmark, and Finland	NTUA, MARIN, ASTANDER, CORE, ESI, TNO, DANAOS, MCGR, TRELL, TUCO (ProZero), SEABILITY, CIRCLE, DNV GL, SAT, Valencia Port, PCT and MHM	MOSES (2020)
AEGIS	Autonomous ships and automated logistics systems	Norway, Denmark, Finland and Germany	Sintef, DFDS, NCL, Aalborg University, DTU, ISE, Grieg Connect, Kalmar, MacGregor, Port of Aalborg, Trondheim Port Authority, Vordingborg Port, and EU	AEGIS (2020)
RAmora and RALamander	Autonomous tugboat	Canada	Robert Allan Ltd.	Robert Allan (2020)
massterly	Autonomous shipping company	Norway	Wilhelmsen and Kongsberg	massterly (2021)

Source: Authors' own elaboration

Table 2. Likert scales used in the questionnaire survey

	1	**2**	**3**	**4**	**5**
Scale 1	Strongly disagree	Disagree	Neither agree or disagree	Agree	Strongly agree
Scale 2	Extremely unlikely	Unlikely	Neutral	Likely	Extremely likely

Source: Authors' own elaboration

Table 3. Job title and professional work experience of participants

	Research Institution/ Academia	Port Authority/ Operator	Ship Owner/ Operator	Logistics Service Provider	Seafarer	Designer / Builder	Local Institution	Total
Job title distribution	46%	20%	17%	6%	4%	4%	4%	100%
Experience								In percentage
1 to 5 years	8	1	0	1	0	0	0	19%
6 to 10 years	9	3	4	2	0	0	0	33%
11 to 15 years	4	2	3	0	1	0	0	19%
16 to 20 years	2	2	0	0	1	1	1	13%
21 to 25 years	1	2	1	0	0	1	0	9%
26 to 30 years	1	1	1	0	0	0	1	7%
Total	25	11	9	3	2	2	2	100%

Source: Authors' own elaboration

Table 4. Kruskal Wallis Test statistics

Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum
Job Title	54	2.2593	1.63897	1.00	7.00
Job Experience	54	2.8704	1.53015	1.00	6.00

Kruskal-Wallis Test

Ranks

	Job Experience	N	Mean Rank
Job Title	1 to 5 years	10	18.20
	6 to 10 years	18	26.00
	11 to 15 years	9	30.39
	16 to 20 years	7	34.64
	21 to 25 years	6	30.08
	26 to 30 years	4	34.63
	Total	54	

Test Statistics[a,b]	
	Job title
Kruskal-Wallis H	7.195
df	5
Asymp. Sig.	0.207

Source: Created by SPSS based on questionnaire survey answers

Table 5. MASS' possible impacts on ports and possible problems in port operations

		Description
Possible Impact	1	Port pilotage services become easier.
	2	Berthing and mooring operations become easier.
	3	Crew is required aboard to vessel for cargo handling preparations (Unlashing/lashing, opening hatch covers, loading/unloading equipment readiness, etc.)
	4	Increase in cargo handling efficiency.
	5	Increase on-shore crew need for cargo handling service.
	6	Documentation related to cargo becomes easier
Possible Problem	7	Autonomous navigation in the port area (e.g., collision avoidance)
	8	Ship-port communication
	9	Remote control access to cargo handling operations
	10	Inadequacy of onshore crew regarding the content of the cargo handled
	11	Testing, verification and validation of characteristics such as quality, quantity and type of cargo handled

***Source*:** Authors' own elaboration

[a]Kruskal-Wallis Test
[b]Grouping Variable: Job experience

Quotes

"Shipbuilders, design offices, shipowners, ports and universities should work closely together."

Quote 1. Operations manager more than 10 years

"There is a need for sharing common research and development between industry and academia"

Quote 2. Academic staff for 5 years

"Autonomous ships can only provide full automation in navigational matters. Cargo operations are a seperate issue. It can be developed without autonomous ships."

Quote 3. Academic staff - more than 10 years

"Port/cargo operations efficiency is not related to the autonomy of the ship. In the whole process of cargo carriage, cooperation and communication between different parties are very important..."

Quote 4. Assistant manager in a shipowning company – more than 10 years

"Public acceptance of high-risk cargoes may be difficult. Passenger ships will likely be impossible to achieve full autonomy."

Quote 5. Marine consultant - more than 10 years

"Cybersecurity becomes more important."

Quote 6. Professor – more than 10 years

"Large investments may be required for tug, pilotage, VTS to manage autonomous ships. With the current outlook, such investments would not yet be wise."

Quote 7. Marine consultant - more than 10 years

"In my opinion, it would be similar to adaption of ports to container terminals. Competition between port operators would force them to invest in new infrastructure for autonomous ships."

Quote 8. Research Assistant – More than 10 years

"Today, among marine ports, being green or digital is an asset in competition. This would evolve to be an "autonomous ship friendly port" in the future, to attract more ships in a more sustainable and efficient way. But this is inevitably difficult and needs not only investments, but also scientific research."

Quote 9. Expert in R&D institution – More than 10 years

The port authority will still be responsible for safe port operations. When a ship cannot safely operate within the port, it should not be allowed to enter the port. Automation should create more safety, to establish that port should invest."

Quote 10. Programme manager of future vessel traffic services – More than 10 years