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Operational adaptation of ports with maritime autonomous surface ships

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ABSTRACT

Preliminary research findings suggest that the successful integration of advanced autonomous technologies in cargo ships could provide safer shipping and provide economical benefits. However, the fact that ships can sail with the assistance of autonomous technologies is not sufficient evidence alone to comprehend the promises of autonomous systems for maritime transport operations. Simultaneously, the entire global maritime transport system must also adapt to the advanced autonomous technologies and act interoperable with ships. In this context, this study aims to examine the areas of interoperability requirements with ports for the effective and integrated operation of autonomous cargo ships. In accordance with the purpose of the study, the operational context in which ships and ports interact is determined, and their interoperability in an autonomous maritime transport scenario is analysed. The present study contains the application of a survey questionnaire reflecting the views of experts dealing with ship and port operations. The data collected by the survey questionnaire are analysed by applying multiple regression analysis methods, utilising the IBM SPSS program. This study is in a pioneer position to define the interoperability characteristics to improve port operations to work in harmony with autonomous ships. The findings of this research are anticipated to contribute significantly to shaping the future of smart and autonomous freight transport and logistics.

1. Introduction

Improvements in advancing technologies are needed to enhance energy efficiency in the maritime transport industry. However, in order to facilitate this successfully, a balance between these newfound technologies and their environmental impact needs to be established in order to create a more economincal, safer and improved maritime transport network (IMO, 2023). Thanks to the increasing development and sophistication of artificial intelligence, machine learning, sensors, and connectivity technologies, autonomous ships have epochal promises for the maritime industry's future and thus attract industrial and academic interest. It is also obvious that a system reducing human-related errors and working without fatigue could offer enhanced maritime transport safety. In addition, more efficient and economically sustainable shipping is only possible with the reduction of crew costs and better savings from the overall total expenditures. Autonomous navigation decisions minimising voyage and port time and fuel consumption would help to reduce the costs of ship operators. To achieve this, data management and analytics gain priority. The collection and processing of weather, traffic, and other related data, thanks to advanced technologies, increases the popularity of autonomous ships. Besides this, autonomous ships, promising efficient operations and environmental benefits, also offer increased carriage capacity and operational flexibility by removing the living space from the design of ships. Overall, the possible advantages can be listed as increased safety, cost-savings, operational efficiency, environmental sustainability, and increased competitiveness, etc (Ghaderi, 2019; Munim, 2019).

The integration of MASS (Maritime Autonomous Surface Ship) with ports and how port operations will be performed on unmanned or reduced crewed ships is another complex issue. While the use of automation/automated systems in terminal operations is common, related ship operations are still carried out with a labour-intensive approach in ports. Navigating and manoeuvring during ship arrival/departure operations under heavy port traffic presents a more multi-layered problem. This problem is mainly shaped around the integration of autonomous systems used by the ship and the port. The combination of seeking more economical and safer maritime transport and the advancements in technology raise the expectations for extensive usage of MASS in the

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Maritime Transport Chain (Wright, 2020).

At the point where the MASS projects have reached today, their implementation into practice does not seem so far away. In recent years, trial voyages of conventional ships equipped with autonomous systems and autonomous ship prototypes have been launched (Beighton, 2021; Liang, 2019; NYK, 2019). Each successful trial voyage has revealed MASS's positive contributions to maritime transport operations and have increased the probability of its promises becoming a reality. In this way, the raising autonomy levels can accelerate, and the benefits of MASS can attract the interests of ship owners. Thus, it is considered that MASS can become widespread in maritime transport with the improving advantages for ship owners. However, even if it is technically possible to sail with MASS in terms of avoiding accidents and following the assigned route (Budak, 2023), integrated interoperability with ports and other coastal systems is essential for sustainable maritime transport. Therefore, ports, which are a critical component of maritime transport, must be integrated with MASS in an operation management manner.

Scientific information is not widely available regarding operational adaptation of ports with MASS due to the lack of research in the academic literature. Therefore, there is a research gap regarding which port operational factors could be influential and essential in the development of interoperability of MASS and ports in an autonomous operation setting. For that reason, this study seeks to answer the research question of how MASS-port operational interoperability can be achieved with the help of outputs from expert opinions based on the key operational factors of an autonomous ship in a port area. The research aim of this study is to support the identification and development of priority areas in the integration of ports with autonomous ships. In this context, the present study is designed with the following research objectives: (1) overviewing MASS development processes and areas of interaction with ports, (2) identification and analysis of MASS-port interoperability areas based on expert opinions in the field of port operations, and finally (3) discussion of solutions for autonomous system integration of ports for efficient sustainability of MASS-port interoperability.

2. Literature review

2.1. Developments in autonomous shipping

It has been observed that there has been significant growth in the literature on the use of autonomous systems in commercial ships since the late 2000s (Munim, 2019). Various conducted case studies and articles on remote control, autonomous ship manoeuvring, and navigation continued to feed the existing literature (Budak and Beji, 2020; Burmeister et al., 2014; Kongsberg, 2017). The results obtained from those studies reveal promising data, which suggests that autonomous or remotely controlled ships can be an important part of maritime transport in the future. Similarly, Makinen (2016) emphasized that smart ships could be the future of the maritime industry and would revolutionize ship design approaches and commercial ship operations. In addition to this foresight, it was predicted that the integration of autonomous systems into maritime transport could create a holistic revolution not only in maritime navigation but also in the entire maritime industry, from shipbuilding to logistics activities and even ship recycling (Gu et al., 2021; Kafali et al., 2022).

Cutting-edge research is necessary to accomplish a transition from conventional shipping to the MASS in practical reality. Several recent projects established a solid technical background for an autonomous maritime ecosystem. For instance, the AUTOSHIP project has accelerated the research motivation on autonomous ships in the EU. The project aimed to achieve competitiveness against the land transportation in coastal short-sea shipping and inland waterways with the developed technologies and technical knowledge (Bolbot et al., 2020). The AEGIS project also proposed a competitive and safe waterborne logistic system design by integrating autonomous ships and automated cargo handling systems in the EU (Psaraftis et al., 2023). The findings from these two projects revealed the importance of trust and reliability of autonomous systems (Rødseth and Wennersberg, 2023). The lack of trust for autonomous systems shaped a system with a leading conventional ship followed by ships using autonomous technologies, as in the Vessel Train project (Meersman et al., 2020). As a result of improvements in this trust, thanks to advancements in smart sensors and data analytics implementations in projects such as ReVolt initiated by DNV, Autosea project of NTNU, and AAWA led by Rolls-Royce, autonomous control systems enable safe navigation avoiding collision risks (Brekke et al., 2019; Rolls-Royce, 2016; Tvete, 2015). Thus, autonomous container ships Yara Birkeland, Suzaku, and Mikage, autonomous ferries Sunflower Shiretoko and Falco, and much more will be able to make their journeys in the global seas and waterways safely (FinFerries, 2018; Kongsberg, 2022; Suzuki, 2021). Additionally, many international and national research project calls with high funding budgets are currently accepting submissions to address challenges regarding autonomous shipping technologies and related autonomous marine ecosystems. Therefore, it is important to enlighten the unknowns of the changing operational needs and systems integration requirements. Innovative technologies that can affect the planning, operation, and operability of commercial and support functions of maritime transport are defined as advanced and analytical autonomous systems, robotics, machine learning, and artificial intelligence (AI) by Egloff et al. (2018). Digitalisation and the Internet of Things (IoT) are other prominent concepts in the maritime transport sector with the development of innovative technologies (Hiekata et al., 2021; Kitada et al., 2018; Plaza-Hernández et al., 2021).

While the digital and automated future ships are bringing significant opportunities (Kretschmann et al., 2017; Reddy et al., 2019), there is also an ongoing debate on the challenges that may be faced by all shipping stakeholders during the adaptation process of new technologies (Dijk et al., 2018; T. Kim et al., 2022; Ringbom, 2019). In addition to the technical difficulties that may be encountered, some barriers may also be revealed due to the distrust for autonomous systems and the lack of awareness, standards, and cooperation among stakeholders regarding the use of new technologies (Tijan et al., 2021). In particular, the possibility of removing on-site human-controlled operations with the transition to MASS can complicate relying on a system that is fully managed by technological devices (Ziajka-Poznańska and Montewka, 2021). Because of the unvalidated benefits and the economic gains of MASS on a larger scale, ship owners may have some drawbacks and act slowly in the transition toward autonomous shipping (Tsvetkova and Hellström, 2022). Safe navigation is indispensable to create trust in MASS technology. It also accelerates the transition towards autonomous shipping. Studies investigating safety risks in navigation are significant in determining potential hazards in autonomous shipping operations. In a recent study, Wan et al. (2023) have modelled the safety risks in a mixed maritime traffic environment to enhance navigational safety. Another study conducted by Li et al. (2023) on autonomous shipping revealed the risks of using MASS from various aspects including safe navigation by reviewing the literature comprehensively.

The sea trial outputs provide important technical data for the transition towards fully autonomous or unmanned ships (FinFerries, 2018; NYK, 2019; YARA, 2021). Furthermore, the statistical analysis carried out by de Vos et al. (2021) reveals that the adaptation of autonomy in ships shorter than 120 m, which accounts the majority of loss of lives and ships, can provide significant safety benefits. However, the transition to full autonomy can only be realised by both technically eliminating safety and security concerns and arranging regulations and legislation on the operation of MASS (Kim et al., 2020; Komianos, 2018). In this context, the roles of crew and autonomous systems in decision mechanisms can be clarified by technically defining the levels of autonomy on the way to full autonomy (IMO, 2018). Thus, a technical basis can be created for the preparation of the relevant regulation and legislation.

It is predicted that the integration of MASS into the maritime transport industry can bring significant operational benefits (Akbar et al., 2021; Kurt and Aymelek, 2022; Levander, 2017). According to recent projects and academic publications, some of the major benefits can be seen as: safer navigation, fuel savings, more environmentally friendly and economical maritime transport, reduced human factor, reduction of crew living space, increased cargo capacity, less operational risk, and tracking of cargo status and machine performance (Burmeister et al., 2014; EU, 2015; Jallal, 2018; Kongsberg, 2022; Levander, 2017; Ziajka-Poznańska and Montewka, 2021).

2.2. MASS-port integration

Transforming the benefits promised by MASS into gains can only be possible if they are integrated into maritime transport smoothly. In other words, MASS should be able to transfer, interpret and use data in a multi-system maritime transport environment without any restrictions in accordance with the definition of interoperability (Rajabifard, 2010).

The development process of autonomous systems used on MASS is directly proportional to the technology's ability to easily connect and exchange information with subsystems in the maritime transport network. Im et al. (2018) emphasize the importance of producing technologies for intelligent information technology (IT) applications by analysing the ship's components, port characteristics, personnel duties, and roles to ensure interoperability. In this context, the integration of interactive components in the maritime transport network into autonomous systems can facilitate adaptation to interoperability. Therefore, recent developments in information and communication technologies encourage the transition to a technical interoperability setting for today's ship-port integration. Panetto and Molina (2008) also stated that the transition from conventional methods to an environment of high-level information and communication, and data-oriented interoperability in the maritime sector is inevitable due to advanced technological developments and market demands. However, intelligent IT-based technical interoperability can also contribute to the design of operational interoperability by creating an efficient operational environment for systems and units (Kasunic, 2001). In this framework, it should be worked on the establishment of technical and operational interoperability within the transition from traditional shipping to autonomy integrated with advanced technologies in response to the demands of the maritime sector to be more economical, environmentally friendly, and safe.

IMO Secretary-General Kitack Lim highlighted that to develop interoperability between MASS and the port, the communication between the ship and the port should increase not only in security issues but also in port services matters (Higgs and Macpherson, 2018). Although the pioneer applications of autonomous systems are envisaged to be implemented on research vessels and offshore support vessels, the trial voyages conducted on cargo ships reveal that it might be feasible to integrate mostly short-range cargo ships into autonomous systems (Burmeister et al., 2014; EU, 2015). Subsequently, promising findings of trial voyages raise expectations for the use of MASS in deep-sea voyages, which is the main market for larger cargo vessels (Grzybowski, 2021). Also, the integration of larger cargo ships into autonomous systems can play an important role in improving the interoperability of global ports with MASS. Global port operators have the potential to provide regular, continuous, and big data on the port operations of MASS, due to both the variety of operations carried out and the size of their scope and scale (Baker, 2018; van den Boogaard et al., 2016). The variety and size of the data obtained from the port operations of MASS can offer significant benefits for the development and improvement of MASS-port interoperability.

Ghaderi (2020) discussed the possible effects of MASS on port operations and emphasizes that the research on the problems of MASS operations in the port industry was limited. The MUNIN project, which aimed to develop autonomous shipping, points out the need for an On-board Control Team (OCT) for MASS's navigational operations in the port area to deal with these potential problems (Rødseth, 2014). So, it was considered that the entrance/exit, berthing, navigation, and manoeuvring of MASS in the port area would be monitored and controlled by an OCT. However, there is a lot of research on remote and autonomous piloting and smart navigation systems that can eliminate the need for OCT, and it provides important outputs that MASS can navigate safely with these systems (Jeong and Kim, 2023; D. Kim et al., 2022; Lahtinen et al., 2020; Wu et al., 2021). On the other hand, however, advanced port automation systems allowed the carrying out of handling operations and in-port transportation operations in container terminals with automatic guided cranes and vehicles (Garrido, 2020). Consequently, a container terminal that was equipped with automated equipment could be operated with 10–15 personnel (Witschge, 2019). However, an autonomous integration where port cranes and port vehicles can interconnect with MASS has not yet been achieved. After the automation of the ports, significant studies were carried out to ensure the integration of autonomous systems on ships. IoT technologies that could enable the interoperability of MASS and ports (Heffner and Rødseth, 2019; Kavallieratos et al., 2018; Komianos, 2018; Statheros et al., 2008). In other words, thanks to a good IoT connection, smooth communication can be established, and cargo can be transported without human intervention. Nybom et al. (2018) mentioned the necessity of IoT technologies by revealing the difficulties associated with the interconnection of vessels with land-based components. Technological concepts in the literature, such as AI, machine learning, and IoT, MASS, e-navigation, smart ports, would take place more frequently in the maritime industry for the widespread of autonomous shipping. In addition, Shore Control Centers (SCC) would also be a component of autonomous shipping to monitor, control and, when necessary, intervene in autonomous shipping (MUNIN, 2016).

Kretschmann et al. (2017) argued that MASS's port operations could not be completely human-free, even if the ships became unmanned. Some operations carried out on board could be performed without the crew with the development of ship automation, however, some other operations are expected to be carried out by a port-based team. It was predicted that this port-based team would especially carry out regular and periodic maintenance of MASS, thus adding a new field of activity to MASS-port interoperability issues (Higgs and Macpherson, 2018). Ghaderi (2020) also stated that several activities carried out by the crew, such as cleaning, stowage, cargo safety and security, could be performed by this port-based team. However, it was stated that the idea of transferring some activities carried out during the cruise to ports with the transition to autonomy might have negative consequences both economically and operationally (Hogg and Ghosh, 2016). Some of these negative results could be defined as an increase in ship port time and average turnaround time, and an increase in berth occupancy rates accordingly.

Although it is desired for ports to increase berth occupancy in terms of efficiency increase, the share of idle times at the port in the berth occupancy rate should be minimized. With the integration of MASS to maritime transport, the inefficiency in port operations can be minimized or eliminated by arranging MASS and port interoperable areas to be compatible with autonomous systems. It is important for the efficiency of the port facilities to have the appropriate technological infrastructure so that they can read the continuous and uninterrupted information provided to the interoperability areas from MASS. It is also required the reduced number of port-based staff and personnel working in the SCC to have the necessary technical skills and abilities to adapt to planning, timing and systematic order (Dybvik et al., 2020; Saha, 2021).

Communication among port authorities and operators, shipping companies, shipping agencies, and technology providers is also essential in ensuring the integration of MASS and port-interoperable areas with autonomous systems (Ahn et al., 2019; Ringbom, 2019). In addition, autonomous system integration at the international level can be supported by the standards to be developed by the maritime transport units of governments and international maritime institutions (IMO, 2023).

Kim et al. (2020) highlighted the importance of developing a collaborative and interoperable culture among these institutions. Komianos (2018) envisaged that the innovations and changes brought by MASS may affect all maritime transport not only in terms of operational but also in terms of legislation and quality.

3. Methodology

3.1. Questionnaire objective

In line with the objective of this study, a survey questionnaire was used to reflect the views of the experts in the shipping and port sector based on their expertise and experience for MASS-port interoperability. Thanks to the data obtained from this survey, it is envisaged that determine the areas of interoperability of MASS and ports and define the aspects that need to be developed to integrate the ports with autonomous shipping. Therefore, the target audience for this survey's participant group is identified as people who are directly associated with ship and port operations. In this direction, a survey distribution channel has been established through the International Association of Ports and Harbours (IAPH), the International Chamber of Shipping (ICS), major ports in the world, and the alumni associations of major maritime universities to access the opinions of experts from global geography. Thus, the concept of "wisdom of the crowd" has been utilized by reaching a large group of participants who can approach port operations from different perspectives to form the best overall decision on a subject where previous studies and individual experts' views are limited. Job titles included in this participant group can be classified as ship owners, port operators, ship operators, shipbuilders, logistics providers, and academics associated with port operations.

3.2. Questionnaire design

The survey was created using Google Forms software, and the survey access link created by the software was sent to the target audience via e-mails. The response collection process from the survey study was carried out between 1 September and 30 September 2022. In accordance with the purpose of the research, two different survey methods were used. These are (I) multiple-choice, and (II) five-category Likert scale. The reason to apply these survey methods was to obtain consistent answers from participants and to facilitate the answer analysis of the questions considering the content and type of questions. Particularly, the Likert scale provides significant benefits in the quantitative evaluation of subjective answers (Joshi et al., 2015). The questions in survey questionnaire were formed to fill the research gap in the very recent conversations in the literature. A similar approach and questions were also used by Kurt and Aymelek (2022), Theotokatos et al. (2023), and Tsvetkova and Hellström (2022).

The questionnaire was prepared in two main parts. The first part includes an explanation of why the survey study is conducted and questions about accessing the demographic information of the participants. The second part, focusing on the main aim of the research, was designed with questions for the determination of MASS-port interoperable areas.

In the ethical consideration of this research, appropriate measures were taken to determine most appropriate data collection method, anonymity, confidentiality, and data protection procedure. The participants were also informed with a participant information/consent form given in the appendix. An inclusion criterion to the study was applied as being an adult, having one of the given five professions and showing strong interest on autonomous shipping.

3.3. Data analysis

In the survey, categorical (nominal), scalar, and ordinal data have been obtained. Nominal data have helped to identify demographic information which does not have a hierarchical relationship with each other such as gender, and occupation of participants. Scalar data have been obtained for the ages of the participants. Ordinal data have been also formed as either quantitative or qualitative as a result of the participants' approaches and ratings on MASS-port interoperability.

The collected data have been analysed in terms of statistical significance and relevance in the IBM's Statistical Package for the Social Sciences (SPSS) program. Then, the Microsoft Excel program has also been utilized for graphical illustrations. Firstly, an analysis has been carried out for the demographic information of the participants. It has been tested whether the different sample averages showed a significant difference from each other by using the nominal values of occupational groups and work experience via the Kruskal-Wallis test. Afterward, a multiple regression analysis of the effects of the multivariate MASS-port interoperable areas on the integration of autonomous systems with port operations has been carried out. While the integration between MASS and ports has been determined as the dependent variable for the regression analysis, the independent variables were defined as the competency of current autonomous system technologies and the sufficiency of conducting R&D projects for level 1. For level 2 multiple linear regression analysis, (I) the communication between MASS and ports, (II) the pilotage service that MASS will receive in the port area, (III) the navigation of MASS in the port area, (IV) the berthing operation of MASS, (V) the documentation works, and (VI) the cargo handling operations have been determined. The dependent variable and independent variables (in two levels), which are used in multiple linear regression, are given in Fig. 1.

MASS-port integration is inevitable for sustainable maritime transport with the proliferation of autonomous ships. Therefore, a model based on MASS-port integration was created as shown in Fig. 1. To investigate the competency of current technologies and the adequacy of R&D studies in terms of establishing and maintaining MASS-port integration, they were defined as the first stage independent variables. Secondary independent variables were determined by referring the port operations, which can be defined as MASS-port interoperable areas. Secondary independent variables cover the entire ship-port interface interaction, from a ship's initial communication with the port to cargo handling operations at berths. The MASS-Port Integration includes the aspects of communication, pilotage services, navigation in port area, berthing/departure, documentation, and cargo handling.

3.4. Profile of participants

The details of the participants' demographic information have been represented in Table 1. Looking at the information on gender, it is seen that 84% of the participants are male, 10% are female and 6% prefer not to say. Age-related data indicate that 60% of the participants are over 40 and the rest are 40 years and under. The occupational profiles of the participants were obtained under five categories which are (I) designer/builder/technology provider (6%), logistics provider (10%), port authority/operator (24%), research institution/academia (40%), and ship owner/operator (20%).

Professional experience in ship-port operations was a crucial aspect in terms of revealing the reliability of the answers obtained. Thus, it can be interpreted that as the professional experience increases, the acceptance validity of the answers given by the participants will increase. The collected answers can be considered as a reliable data source due to particular attention is paid to reach to industrial survey participants having mid-level to senior-level position or a job title. The detailed distribution of the participants' professional experience by occupation is given in Table 2.

Since the number of participants in the occupational groups is low in terms of statistical calculations, it was not possible to provide parametric test assumptions. Therefore, a non-parametric Kruskal-Wallis analysis of variance was applied. Thus, it will be understood whether there is a significant difference depending on the job title and experience. The

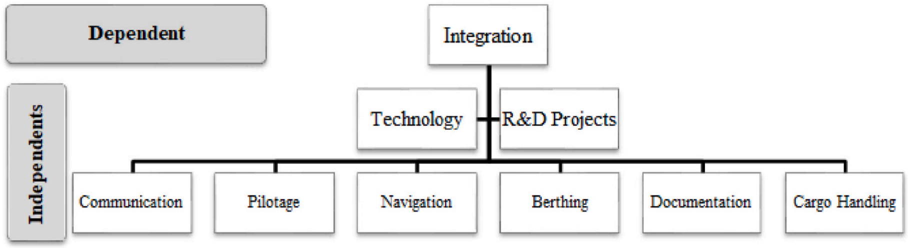

Fig. 1. - Dependent and independent variables in regression analysis.

Table 1
– Demographical information of survey participants.

	N = 50	%
Gender		
Female	5	10%
Male	42	84%
Prefers not to say	3	6%
Age		
21–30	7	14%
31–40	13	26%
41–50	18	36%
51–60	12	24%
Occupation		
Designer/Builder/Technology Provider	3	6%
Logistics Provider	5	10%
Port Authority/Operator Member	12	24%
Research Institution/Academia	20	40%
Ship Owner/Operator	10	20%

applied Kruskal-Wallis Analysis of Variance results are given in Table 3. As a result of the analysis, the asymptomatic significance (asymp. sig) of Kruskal-Wallis has been found as 0.723. It can be said that there is no significant difference in the distribution of the occupational groups due to the asymp. sig of $0.723 > 0.05$ (significance level 5%). Therefore, it revealed that the answers given by the respondents do not differ significantly according to the job title and experience, and it can be concluded that the data obtained are reliable.

It can be said that participants with different occupational groups and experiences can agree on a common view, especially in this study on autonomous maritime transport, which is at the R&D stage. Therefore, the views of the participant group should be considered valuable in determining the port and MASS interoperability areas.

4. Results

Firstly, the necessity of technical and operational MASS-port integration for the realization of autonomous maritime transport has been investigated. In this respect, the detailed representation of the answers collected from the participants is given in Fig. 2. Accordingly, while more than half of the participants (52%) agree that there is such a necessity, 32% remain neutral and only 14% do not consider MASS-port integration for autonomous shipping as a necessity.

It can be said that the establishment of MASS-port interoperability will be possible with sustainable technical and operational integration. The opinions of industry stakeholders, that the level of development of current technologies and R&D studies can ensure this integration smoothly, will facilitate the transition to autonomy. Therefore, questions were asked to the sectoral survey participants whether the current technologies are competent and R&D studies are sufficient to enable MASS-port integration. A detailed presentation of the data obtained is given in Fig. 3. As a result of the analysis of the collected data, only 28% of the participants think that current technologies can enable MASS-port integration. While 26% of the participants remain neutral, 46% find the competence of current technologies insufficient. Similarly, while only 16% of the participants found R&D studies sufficient for MASS-port integration, the ratio of those who found it neutral and insufficient was 32% and 52%, respectively.

Multiple linear regression analysis was conducted to understand and explain the regression of the MASS-Port integration dependent outcome variable with the responses to level 1 independent variables (Model 1). Level 1 multiple regression analysis results are given in Table 4.

Table 4 also presents the model summary that can be used to understand how well the run regression model fits the data with the values of R, R^2, $R^2_{adjusted}$, and *standard error of the estimate*. In Model 1, there is more than one independent variable so $R^2_{adjusted}$ is referred to explain the variance of independent variables for the dependent variable. It can be thought that the adjusted $R^2_{adjusted} = 0.114$ value obtained in Model 1 is small to explain the improvement of MASS-port integration with *current technologies* and *R&D studies*. But as Frost (2017) specifies, while small R^2 values aren't always a problem, high R^2 values aren't necessarily good. Because the propositional hypothesis "*MASS-port integration is a necessity for autonomous shipping*" was questioned to collect data for the dependent variable. For the independent variables, the propositional hypotheses "*The competency of current technologies are sufficient for the transition to autonomous shipping*" and "*R&D projects are sufficient to develop autonomous shipping*" were questioned, respectively. Therefore,

Table 2
– The distribution of the participants' professional experience by occupation.

	Research Institution, Academia	Port Authority, Port Operator	Ship Owner, Ship Operator	Logistics Provider	Designer, Builder, Technology Provider	Total
Occupation distribution	40%	24%	20%	10%	6%	**100%**
Experience						**Percentage**
1–5 years	4	1	0	1	1	14%
6–10 years	9	3	4	2	0	36%
11–15 years	4	3	2	0	1	20%
16–20 years	2	1	1	1	1	12%
21–25 years	1	2	1	1	0	10%
26–30 years	0	2	2	0	0	8%
Total	**20**	**12**	**10**	**5**	**3**	**100%**

Table 3
– Kruskal-Wallis test statistics.

Descriptive Statistics					
	N	Minimum	Maximum	Mean	Std. Deviation
Job Title	50	1,00	5,00	3,5800	1,10823
Experience	50	1,00	6,00	2,9200	1,48241

Kruskal-Wallis test

Ranks

Experience		N	Mean Rank
Job Title	1–5 years	7	20,64
	6–10 years	18	28,44
	11–15 years	10	25,85
	16–20 years	6	21,50
	21–25 years	5	22,20
	26–30 years	4	30,00
	Total	50	

Test Statistics[a,b]

	Job Title
Kruskal-Wallis H	2854
df	5
Asymp. Sig.	0,723

[a] Kruskal Wallis Test.
[b] Grouping Variable: Experience.

$R^2_{adjusted}$ explains that there is a linear regression between the independent variables and the dependent variable at a ratio of 11.4. In other words, 88.6% (100%–11.4%) of the variations find inadequate *current technologies* and *R&D studies* to ensure the necessary MASS-port integration. Therefore, it can be said through this analysis that the increase in the competence of current technologies and the proliferation of R&D projects will make significant contributions to the development of MASS-port integration.

The multiple regression results together with the coefficients model outputs obtained can be evaluated as follows. Model 1 statistically significantly predicted MASS-port integration F (2, 47) $= 4.141$, p (0.022) < 0.05, $R^2_{adjusted} = 0.114$. Accordingly, the *"current technologies"* predictor predicts MASS-port integration positively and significantly, $\beta = 0.326$, t (47) $= 2.095$, p (0.042) < 0.05, $pr^2 = 0.085$. However, the "*R&D projects*" predictor does not significantly predict MASS-port integration when the *"current technologies"* predictor is already in the model, $\beta = 0.101$, t (47) $= 0.647$, p (0.521) > 0.05, $pr^2 = 0.009$. The multicollinearity problem does not exist in Model 1 as $VIF < 10$ (or $Tolerance > 0.1$) for all predictors. As a result of the obtained outputs, the regression equation of Model 1 can be written as follows.

$$Integration = 2.554 + 0.3 \times Current\ Technologies + 0.097 \times R\&D\ Projects$$

Thanks to this equation, it will be possible to predict the opinion of a new expert on the subject on *"MASS-port integration is a necessity for autonomous shipping"* by the answers given about *"The competency of current technologies are sufficient for the transition to autonomous shipping"* and *"R&D projects are sufficient to develop autonomous shipping"* using the Likert Scale.

Another multiple linear regression analysis was also conducted to understand and explain the regression of the MASS-Port integration dependent outcome variable with the responses to level 2 independent variables. These are (I) communication, (II) pilotage, (III) navigation, (IV) berthing, (V) documentation, and (IV) cargo handling. Statistical outputs of the Level 2 multiple regression analysis model (Model 2) are given in Table 5.

As a result of the analysis, it was found that a significant regression model F (6, 43) $= 5.942$, $p < 0.05$ and 38% of the variance ($R^2_{adjusted} = 0.377$) in the dependent variable were explained by the independent variables. Accordingly, only one predictor *"documentation"* predicts the dependent variable positively and significantly. The analysis values obtained for the *"documentation"* predictor is as follows.

- *"Documentation"*: $\beta = 0.556$, t (43) $= 3.431$, p (0.001) < 0.05, $pr^2 = 0.215$

However, other independent variables cannot predict the dependent variable significantly. The analysis values obtained for these independent variables are as follows.

- *"Communication"*: $\beta = 0.039$, t (43) $= 0.268$, p (0.790) > 0.05, $pr^2 = 0.002$
- *"Pilotage"*: $\beta = -0.122$, t (43) $= -0.461$, p (0.647) > 0.05, $pr^2 = 0.005$.
- *"Navigation"*: $\beta = 0.082$, t (43) $= 0.516$, p (0.608) > 0.05, $pr^2 = 0.006$.
- *"Berthing"*: $\beta = 0.310$, t (43) $= 1.381$, p (0.174) > 0.05, $pr^2 = 0.042$.
- *"Cargo handling"*: $\beta = -0.121$, t (43) $= -0.726$, p (0.472) > 0.05, $pr^2 = 0.012$.

As a result of the obtained outputs, the regression equation of Model 2 can be written as follows.

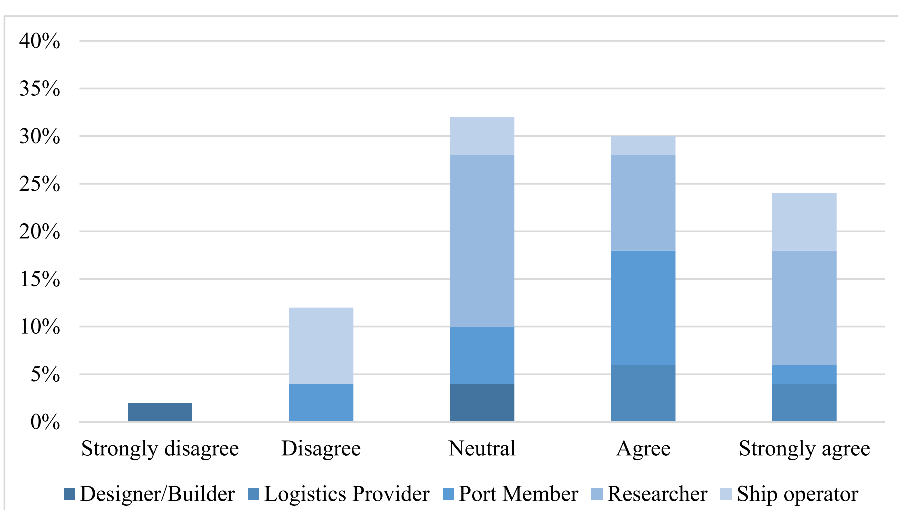

Fig. 2. – Necessity of MASS-port integration for autonomous shipping.

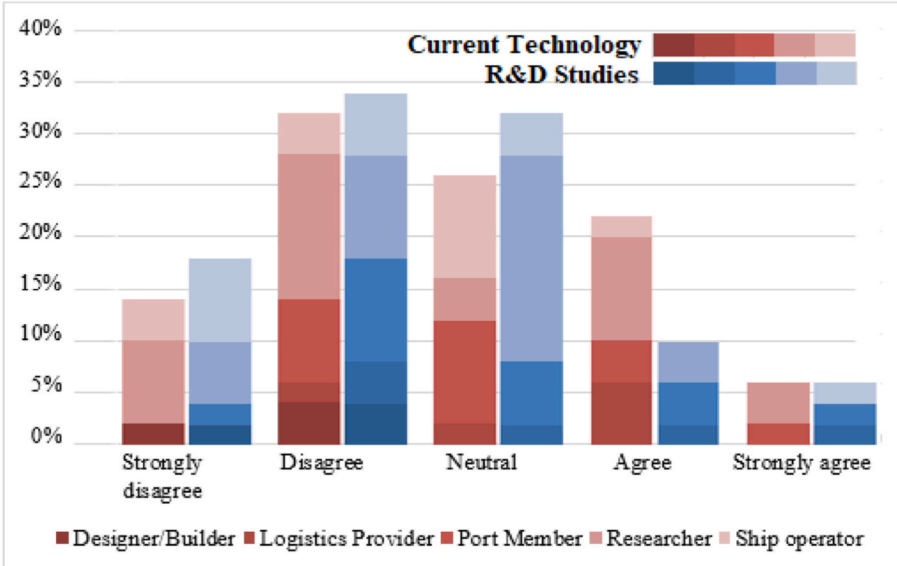

Fig. 3. – The competency of current technologies and sufficiency of R&D studies.

Table 4
– Level 1 multiple regression analysis results.

Descriptive Statistics

	Mean	Std. Deviation	N
Integration	3,6200	1,04764	50
Current Technology	2,7400	1,13946	50
R&D Projects	2,5200	1,09246	50

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0,387[b]	0,150	0114	0,98633

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	8056	2	4028	4141	0,022[b]
	Residual	45,724	47	0,973		
	Total	53,780	49			

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95,0% Confidence Interval for B		Correlations			Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	2554	0,408		6267	0,000	1734	3374					
	Current Technology	0,300	0143	0,326	2095	0,042	0012	0,588	0377	0,292	0282	0,746	1341
	R&D Projects	0,097	0149	0,101	0647	0,521	−0,204	0397	0,265	0094	0,087	0746	1341

a. Dependent Variable: Integration

[a] Dependent Variable: Integration.
[b] Predictors: (Constant), R&D Projects, Current Technology.

$$Integration = 1.770 + (0.036 \times Communication) + (0.082 \times Navigation) + (0.268 \times Berthing) + (0.442 \times Documentation) - (0.108 \times Pilotage) - (0.123 \times Cargo\ handling)$$

Thus, the estimation of the integration dependent variable describing MASS-port integration based on an expert's quantitative Likert scale views on the independent variable defined for six port operations can be done with the Model 2 regression equation.

5. Discussion

The results obtained in this study show that, the competence of the current technologies and the adequacy of the R&D studies carried out to date also contain certain doubts about the transition to autonomous maritime transportation. However, concerns in extending autonomy are not solely technology based. There are also administrative concerns. Eronen (2023) states that concerns about international regulations regarding autonomous ships, liability issues and the development of the necessary infrastructure should also be addressed. The International Maritime Organization (IMO) is conducting regulatory discussions on

Table 5
- Level 2 multiple regression analysis results.

Descriptive Statistics

	Mean	Std. Deviation	N
Integration	3,6200	1,04764	50
Communication	3,4000	1,16058	50
Pilotage	3,4400	1,18080	50
Navigation	3,5510	1,05097	50
Berthing	3,2800	1,21286	50
Documentation	3,0600	1,31568	50
Cargo handling	3,4200	1,03194	50

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
2	0,673[a]	0,453	0377	0,82689

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
2	Regression	24,379	6	4063	5942	0,000[a]
	Residual	29,401	43	0,684		
	Total	53,780	49			

Coefficients[b]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95,0% Confidence Interval for B		Correlations			Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
2	(Constant)	1770	0,589		3002	0,004	0581	2958					
	Communication	0,036	0133	0,039	0268	0,790	−0,232	0304	−0,040	0041	0,030	0587	1704
	Pilotage	−0,108	0235	−0,122	−0,461	0647	−0,581	0365	0,534	−0,070	−0,052	0182	5501
	Navigation	0,082	0158	0,082	0516	0,608	−0,237	0401	0,027	0079	0,058	0505	1982
	Berthing	0,268	0194	0,310	1381	0,174	−0,123	0659	0,503	0206	0,156	0252	3963
	Documentation	0,442	0129	0,556	3431	0,001	0182	0,702	0639	0,464	0387	0,485	2062
	Cargo handling	−0,123	0169	−0,121	−0,726	0472	−0,465	0219	−0,057	−0,110	−0,082	0456	2192

[a] . Predictors: (Constant), Communication, Pilotage, Navigation, Berthing, Documentation, Cargo handling.
[b] . Dependent Variable: Integration.

autonomous ships, which also aims to eliminate administrative concerns (Ringbom, 2019). As a result of the positive outputs to be obtained from the autonomous shipping projects and research, it is of great importance to eliminate these doubts with the advancement in the competence of the technologies to be used in autonomous shipping (Komianos, 2018; Lee, 2020).

Developing autonomous navigation systems alone is not enough for sustainable autonomous shipping. Of course, it is a very valuable promise for the transition to autonomous shipping that an autonomous ship can avoid collisions on a planned route and reach the determined destination by reducing or eliminating the human factor (Chun et al., 2021). However, since maritime transport represents an ecosystem formed by many parties, integration with other parties cannot be ignored for sustainable autonomous shipping. While Tsvetkova and Hellström (2022) emphasize the need to develop complementary infrastructure and activities in the maritime transport ecosystem, it is revealed that it is important to develop port activities, which are analysed in this study, in the adaptation of ports with MASS as a part of autonomous shipping ecosystem.

With the expansion of MASS in shipping, port area manoeuvres, port berthing, and cargo operations will also emerge as a challenge for sustainable autonomous shipping (Kurt and Aymelek, 2022). This is due to the need for overcoming the operational barriers in the non-existence of onboard ship crew. These barriers include collision risk with other ships, floating objects, obstacles, and coastal structures. They also cover port area specific manoeuvring and berthing actions, cargo operation safety, documentation of operations, and most importantly efficient ship to port communication. If the discussion is deepened through the analysis outputs obtained, it is believed that the document flow between autonomous ships and ports can be significantly facilitated with a smooth MASS-port integration. The underlying reason for this is the widespread use of internet technologies and the potential for a paperwork decrease. However, in operational order, communication between MASS and ports, port pilotage services of MASS, navigation of MASS in port areas, berthing of MASS at ports and cargo handling are foreseen as challenges separately under current circumstances. These are expected as challenges because of the inadequacy of the technological infrastructure that can provide MASS-port integration, and the fact that it has not been properly tested and validated. In addition, the fact that "*Pilotage*" and "*Cargo handling*" have a negative coefficient in the Model 2 regression equation is because these operations will be carried out by an external party, not by the autonomous ship's own systems.

The methodological application of this study includes various benefits including making an evaluation of variables and linking between variables in multiple regression. On the other hand, the quantitative analysis methodology used in this study has some limitations as it is accepted that there are some assumptions on the basis of it.

It is not possible to establish interoperability between MASS and ports in case of failure to provide MASS-port integration in terms of port operations, which are defined as the independent variables in this study. Disruptions caused by technological innovations trigger adaptive evolutions. The expected possible disruptions in the context of MASS use could also help port operations and maritime ecosystem to develop more smart and autonomous adaptive evolutions. It is predicted that this trend not only would enable automation and digitalisation of ports but also would increase technological developments in smart port concept. The overall smart and autonomous integration of interdependent systems in maritime transport chain will increase the efficiency and sustainability of global logistics and supply chain management.

6. Conclusion

Although it is considered insufficient in this study, autonomous ship research carried out in recent years reveal important findings regarding the feasibility of autonomous shipping. Autonomous ships offer many economic and environmental promises, but they also raise some concerns. Safe and secure navigation, and sustainability are at the forefront of these concerns. In fact, the integration and interoperability with other parties are other challenges for the operational sustainability of autonomous shipping. Therefore, the development of autonomous interoperability with ports where a ship spends a significant part of its life cycle will accelerate the widespread use of autonomous ships.

With this motivation, this study presents the opinions and expectations of port stakeholders on autonomous shipping to develop an integrated port operation, particularly in MASS-port interface areas. The most obvious finding of the study is that there will be a need for MASS-port integration in terms of documentation, berthing, cargo handling, pilotage, navigation, and communication respectively, to carry out a viable autonomous maritime transport. However, the results of this study also indicate some concerns about the competency of current technologies and the adequacy of R&D studies to ensure MASS-port integration. As an implication of this, the validation and test applications of developed autonomous system technologies should prove themselves to attract the industry's interest in autonomous shipping. More comprehensive research will also help to enlighten many dark areas of Autonomous maritime transport operations. Overall, this study strengthens the idea that integrating information technologies, digitalisation, and autonomous systems into port operations such as communication, pilotage, manoeuvring, berthing, documentation, and cargo handling will facilitate the management of MASS and ports' interoperability areas.

Since the findings of this study include the opinions of port operations experts, the idea that MASS-port integration is necessary for sustainable autonomous shipping is backed and confirmed by expert opinions on conventional port operations. Although the opinions included in the study are taken from the experts, the personal perceptions of the experts regarding the MASS can be defined as a limitation of this study. Mainly the answers obtained via survey questionnaire reflect the personal opinions of the experts on the subject due to the absence of widespread use of autonomous ships. Therefore, it can be said that the absence of widespread use of autonomous ships is another limitation of the study. Consequently, it was not possible to collect MASS's actual port operation data to assess MASS-port interoperability. Despite its limitations, the study certainly contributes to our understanding of the MASS-port integration which should be provided in the interoperability areas of ships and ports.

As this study is one of the preliminary types of research regarding the operational adaptation of ports with autonomous ships, it has thrown up many questions in need of further research. One of them should specifically relate to the diversification and more detailed consideration of MASS-port interoperable areas. Another future research should include addressing possible practical problems that may occur in MASS-port interoperable areas. More field-based information on MASS port operations would help us to establish a greater degree of accuracy on this matter. Using the data collected in this study, possible further research should be conducted on evaluating differences between stakeholder perspectives involved in this research. The discrete choice modelling methods are considered as the most appropriate methodologies to perform such stakeholder perspective analysis in detail.

Author statement

Ismail Kurt – Investigation, Conceptualization, Methodology, Data Collection, Formal analysis, Resources, Writing - original draft, Funding acquisition Murat Aymelek – Investigation, Formal analysis, Resources, Writing - original draft, Writing – review & editing.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tranpol.2023.09.023.

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