

Research article

From concept to practicality: Unmanned vessel research in China

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ABSTRACT

Maritime Autonomous Surface Ships (MASS) have received increasing attention from industrial practitioners, researchers, and policymakers because of industry 4.0 and the digitization of the maritime industry. Crucial questions related to security, safety of personnel and vessels, and socio-economic domains have been addressed to a certain extent. In recent years, China has arisen as one of the leading maritime players worldwide, and unmanned vessels could remarkably influence the Chinese maritime industry. However, there is still a lack of systematic studies aiming to develop a deep understanding of potential advantages and challenges associated with the deployment of unmanned vessels in China. Therefore, using a mixed-method research design, this study attempts to obtain valuable insights based on the viewpoints of the key Chinese stakeholders concerning unmanned vessels, including the benefits, the restrictions, the obstacles to large-scale implementation, the risks, and how to mitigate possible implementation barriers. The main advantage of deploying unmanned ships was found to be the reduction in the ship crew size or complete elimination of the ship crew, which would reduce the operating costs and eliminate human errors on board the ships. Nevertheless, along with important advantages, a number of challenges associated with the development and deployment of unmanned ships were identified, including technological challenges, regulatory challenges, safety and security challenges, and technology investment challenges. All these challenges have to be adequately addressed by the relevant stakeholders to ensure the successful deployment of unmanned ships around the globe in the following years.

1. Introduction

Maritime transport carries over 80% of the globally traded cargo [1]. In the context of the maritime industry, liner shipping firms encounter stiff competition and thus reduce operational costs to sustain target profit margins in a competitive business environment. In general, the crew cost generates around 5–15% of vessel operating costs. Indeed, a cost-cutting exercise with respect to the crew size is not expected to negatively affect vessel seaworthiness. Savings may be attained by decreasing the number of crew members and

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recruiting them from low-income countries, in which seafarers are expected to receive a lower salary. This may be shown by comparing the size of crews on vessels today in contrast to their numbers in the past decade. Nowadays, 5000-car capacity ro-ro vessels, 8000-TEU container vessels, and 210,000–405,000 DWT bulk carriers are operated by around 20–22 seafarers on the assumption that the seafarers are employed from the five biggest maritime nations (i.e., China, India, Indonesia, the Philippines, and Ukraine) or around 14–16 seafarers assuming that the seafarers are recruited from higher-income nations. In the 1980s, vessels of the same size would require around 30–40 seafarers due to the heavy workload on board.

Supporters of the autonomous vessel technology, such as Kongsberg Gruppen, Wartsila, and Rolls-Royce, suggest that unmanned vessels could minimize human errors and decrease the operational costs related to the personnel cost. In the past 30 years, the International Maritime Organization (IMO) and other maritime industry stakeholders have witnessed a decreasing number of crew members who may cause adverse fatigue-related safety problems. Vessels with advanced levels of artificial intelligence and automation can potentially serve as the “silver bullet” in addressing the aforementioned matters [2]. Due to their potential advantages, unmanned vessels have started receiving more and more attention over the past years. Unmanned vessels can be deployed in civil and military fields (see Fig. 1). Civil applications of unmanned vessels include, but not limited to, marine environmental monitoring, maritime search and rescue, fishery administration supervision, marine fishery farming, and fishing. Military applications of unmanned vessels include, but not limited to, port patrol, port mine clearance and demining, anti-terrorism investigation, and fire support.

A number of research studies have been conducted over the past years, aiming to investigate the development of autonomous ships in China and other countries as well. As an example, Chase et al. [3] discussed the emerging trends in the development of autonomous ships in China by using the available published resources. Jovanovic et al. [4] researched the economic feasibility of autonomous shipping. Razmjooei et al. [5] performed a systematic review of industry 4.0 research in the maritime industry. However, the study only provided a general discussion about the concept of autonomous ships and research trends. Sun and Ho [6] proposed path-planning algorithms to prevent collision of unmanned ships and design optimal route planning. Guan et al. [7] adopted a behavior decision-making model to investigate the safety of autonomous ships. Koo et al. [8] presented an architectural design to facilitate the access of autonomous ships to multiple radio networks and optimize route planning. Zheng et al. [9] developed a receding horizon navigation and control system for unmanned vessels to minimize carbon emissions and fuel costs under safe ship operations. Nevertheless, the previous research studies have a number of methodological shortcomings.

In particular, most of the previous research studies mainly discussed the deployment of unmanned ships, concentrating on path planning, collision avoidance, economic feasibility, and carbon emissions. Indeed, the deployment tendencies of autonomous ships in China, notably the attitude and perception of the Chinese maritime stakeholders towards unmanned ships, are under-researched. To address this research gap, the present study attempts to investigate the industry viewpoints about the challenges and benefits of using autonomous ships through conducting a series of surveys and interviews with a diverse group of informants, who are represented by different Chinese maritime stakeholders. This study primarily focuses on the Chinese maritime industry since it is one of the world's largest shipbuilding states, and one of the few nations that heavily invest in the development of unmanned ship technology. The Chinese marine researchers and scientists developed unmanned ships that can navigate autonomously and be controlled remotely in open waters. Indeed, China launched the first unmanned ships to perform remote control and autonomous navigation functions in the world [10].

The next sections of this manuscript are organized in the following order. The remainder of Section 1 provides more background information regarding Maritime Autonomous Surface Ships (MASS), current developments of MASS, and the key research gaps addressed by this study. Section 2 elaborates on the data and methods that were used throughout this study. Section 3 provides more details regarding the main findings from the present research, focusing on the attitudes of Chinese maritime stakeholders towards the deployment of unmanned ships, the interconnection of system elements of unmanned vessels, and the main advantages of unmanned ships. The major challenges associated with MASS and future prospects are discussed in Section 4. Section 5 summarizes the present research outcomes and provides a set of recommendations for scientists and practitioners.

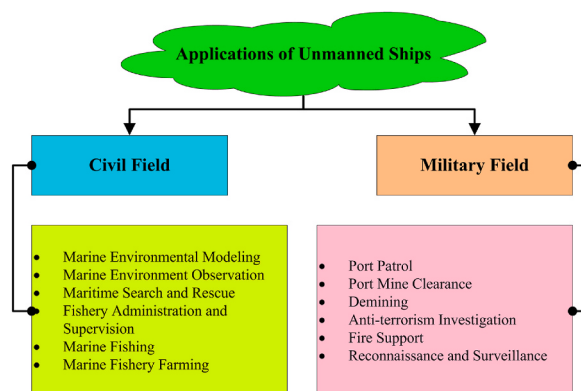


Fig. 1. The main application areas of unmanned vessels.

1.1. Maritime Autonomous Surface Ships

Maritime Autonomous Surface Ships (MASS) is a term used by the IMO to describe a surface ship that is capable of operating without humans on board [11]. These unmanned ships should be distinguished from unmanned submarine vehicles that are commonly used in the offshore industry. Since 2017, the Maritime Safety Committee (MSC) of the IMO has been exploring the use of unmanned ships for commercial cargo and passenger use. In 2017–2018, the MSC completed an initial scoping exercise on the subject and discussed its findings in MSC's 98th and 100th sessions, respectively [11,12]. We are aiming to examine the MSC's scoping exercise and explore the perceptions of Chinese shipowners, managers, operators, and seafarers regarding the benefits and limitations of MASS technology.

Safety standards in the maritime industry are regulated by the IMO and flag state legislations. Maritime accidents, such as the grounding of *Exxon Valdez* off the Alaskan coast and the capsizing of *Herald of Free Enterprise* off the European coast, can have devastating economic and environmental implications. They can also result in injuries, deaths, and damages to property. Maritime industry regulators are constantly revising education and training standards to reduce the risk of maritime accidents, which are mostly caused by human errors due to fatigue or lack of knowledge. Unmanned ships are expected to prevent human errors and hazardous situations at sea, as no crew is expected to be on board (although certain commands still can be sent to the ships from onshore stations).

The marine safety of unmanned ships is very important, and many scholars have conducted research on safety-related issues. Zhou et al. [13] adopted a systems engineering approach to establish system safety requirements and performance criteria, considering the characteristics of autonomous ships. Chang et al. [14] developed a method to assess the risk level of the main hazards associated with MASS. Fan et al. [15] proposed a risk-based framework to compare the risks related to different situations. Sepehri et al. [16] analyzed the role of shipping 4.0 technologies in controlling the risk of shipping accidents and integrated the findings into a conceptual framework to guide future developments. Advanced accident modeling and risk assessment methodologies have been recently developed with an objective of improving ship safety [17,18]. Among various safety factors, the human factor is particularly important in the development of unmanned ships. Some scholars have conducted research on human factors and unmanned ship operations. Wahlström et al. [19] presented an overview of challenges rising from human factors for the future onshore control centers of unmanned ships. Abilio Ramos et al. [20] analyzed the human factors as the key factors for the successful collision avoidance in MASS operations. Ramos et al. [21] presented an autonomous human-machine interaction approach for MASS crash scenarios and illustrated its application through a case study. Narayanan et al. [22] argued that the gradual adoption of MASS and shipping 4.0 would play an important role in increasing the participation of women in the shipping sector.

There are many different methods to study the maritime navigation of unmanned ships and associated risks, including the risk modeling analysis and unmanned ship accident modeling. Wróbel et al. [23] evaluated the safety of unmanned ships through maritime accident reports, and the results showed that the occurrence of navigational accidents could be reduced due to the development of unmanned ships. Fan et al. [24] proposed a framework for identifying the risk factors for MASS navigation that can be used in any risk and safety analysis associated with remotely controlled MASS. Utne et al. [25] proposed a framework for online risk modeling of autonomous ships to improve the decision-making capabilities and intelligence of such systems. Guo and Utne [26] proposed a method based on the Bayesian Belief Network (BBN) to identify the risk indicators. Li et al. [27] identified potential operational risks of MASS and examined their intertwined causality using network modeling.

Many scholars have also conducted research on the modeling of unmanned ship sailing accidents. Thieme et al. [28] assessed the risk of MASS navigation through a ship collision risk model. Huang et al. [29] proposed an HMI-Oriented Collision Avoidance System (HMI-CAS) framework for the interaction between humans and autonomous surface ships at sea. Ramos et al. [21] presented an autonomous human-machine interaction (H-SIA) approach for MASS crash scenarios and illustrated its application through a case study. Zhang et al. [30] systematically expounded that the fully autonomous collision avoidance navigation of MASS in complex environments still faces huge challenges, thus highlighting the development trend of maritime collision avoidance navigation systems. Bolbot et al. [31] argued that collision avoidance (CA) systems constitute a key enabling technology for MASS, and that their proper functionality is essential to ensure safe navigation. Kim et al. [32] developed the Samsung Autonomous Ship (SAS) system to avoid ship collisions. Öztürk et al. [33] reviewed path planning algorithms for autonomous maritime vehicles and their collision rule dependencies to shed light on how the research community approaches this problem. A number of studies were also conducted to explore the use of deep learning methods combined with Automatic Identification System (AIS) data to conduct research on unmanned ships [34,35].

1.2. Current developments - case of Yara Birkeland

An unmanned vessel is a seagoing vessel that is equipped to operate without a physical crew on board [36]. Some applications would require a small-size crew on board to oversee the functioning of the autonomous systems, and other applications may not require a crew at all. A vessel that can sail without a crew would seem to be commercially desirable since it could significantly reduce operational costs and increase safety by eliminating the risk of human errors. MUNIN [37] argued that replacing human elements on board with automated systems could remarkably decrease the occurrence of maritime accidents. However, there are counterarguments that autonomous ships are extremely expensive to build, and current "demonstration ships" could be built and developed only due to large government grants and subsidies.

A good example is the 120-TEU fully electric unmanned container ship built in 2020, called *Yara Birkeland* (IMO 9865049). The majority of the funds used to build *Yara Birkeland* were obtained from the Norwegian Ministry of Climate and Environment. The NOK 134 million (equivalent to USD 16.7 million) grant was funded by "Enova SF", an enterprise owned by the Norway's Ministry of

Petroleum and Energy [38]. This grant accounts for over half of the ship's total cost of NOK 250 million (USD 29 million) [39]. Thus, arguments supporting the financial benefits of autonomous ships are contentious since the price of Yara Birkeland amounts to nearly the price of a conventional ultra-large container ship with a much larger carrying capacity. Yara Birkeland took about 3 years to build (2018–2020), while a conventional ship of similar size would take about 8 months to build. Yara Birkeland had to sail under manned operations for two years, after which it was expected to gradually transition to unmanned operations. The ship is designed for very short (less than one-day duration) coastal passages in the area with very low vessel traffic off the Norwegian coast. It is intended to replace the trucks that currently transport chemicals between the Ports of Brevik and Larvik in Norway (see Fig. 2). Yara Birkeland was completed and set to sail in 2021. This ship is recognized as the world's first autonomous and fully electric container ship in the >10 TEUs category [40,41].

Unmanned ships require continuous remote troubleshooting and monitoring by specialized shore-based service providers. These services in addition to the advanced technology and machinery may contribute to unmanned ships having far higher operational costs than conventional manned ships. Some also argue that unmanned vessels could make navigating seas more unsafe if the technology is not properly adapted to suit areas that have exceptionally high traffic, such as the Panama Canal, the Suez Canal, the Singapore straits, and the coasts of China, Japan, Korea, Sri Lanka, India, Thailand, and Vietnam. The Rolls Royce engineering team has been developing autonomous vessel capabilities, and they believe that fully automated ships will be widely deployed by the year of 2030 [42].

The prospect of transitioning to the use of unmanned ships faces practical real-world challenges. As of 2020, there were a few fully operational unmanned ships carrying out regular services. While some demonstration voyages have been undertaken since 2016, they have generally either been “test voyages” of very small-sized ships under highly controlled sea and voyage conditions or “experiments”, in which certain systems operated fully autonomously for a period of time after which they reverted back to their conventional mode of manned operation. Situational awareness, alerts, and communication are necessary for preventing marine incidents. While the use of unmanned ships aims to eliminate human errors by replacing humans with machines, software, and automation, it could be argued that the *removal* of the human element from the vessels may *undermine* the safety of maritime operations [43]. Human beings are highly inventive personnel who continuously adapt to changing scenarios instinctively. The maritime environment itself is highly diverse and changes rapidly in the same sea area, with vast differences in operational conditions across the world and even in the same sea area within a few nautical miles for certain locations. Thus, the criteria for identifying dangers are an integral part of collision avoidance, which requires bridging between theoretical and real-life scenarios. In the absence of a regulatory framework, managing the interaction between unmanned and conventional ships will add to the challenges facing this novel technology [44]. Additionally, the operation of unmanned ships also carries the risks of cyber-security attacks, system failure, piracy, and data management issues [45].

In recent years, China has emerged as the world's largest shipbuilder, largest seafarer-supplying country, largest port state, and the third largest shipowner [46]. The earliest unmanned ship project was started by China State Shipbuilding Corporation Limited (CSSC) in 2014 [47], and by December 2018, China had commissioned the world's largest unmanned ship test site [48]. On December 16th 2019, China's first autonomous cargo ship, *Jin Dou Yun 0 Hao* (see Fig. 3 [48]), completed its first trial voyage along the coast of Guangdong and Shenzhen in Southern China. Indeed, *Jin Dou Yun 0 Hao* and Yara Birkeland can be viewed as some of the most recent achievements in the development of unmanned ship research and technologies (see Figs. 4 and 5).

In this context, our research team posed the following key research questions: 1) What are the opinions of the major stakeholders in China regarding the development of unmanned ships, and what justifies their responses; and 2) Which major challenges are delaying the immediate transition to unmanned ships in the global seaborne trade? This paper seeks to answer these questions to help filling the existing knowledge gap and provide some valuable inputs for academicians and practitioners.

1.3. Aims and research gaps

With the significant changes that are expected to occur, technological advancements must be adapted and applied in the maritime industry [39]. Advocators of MASS reinforce that the adoption of autonomous technologies may perhaps decrease the industry's reliance on the crews from developed countries [49]. Nevertheless, the following three main factors threaten the trustworthiness of

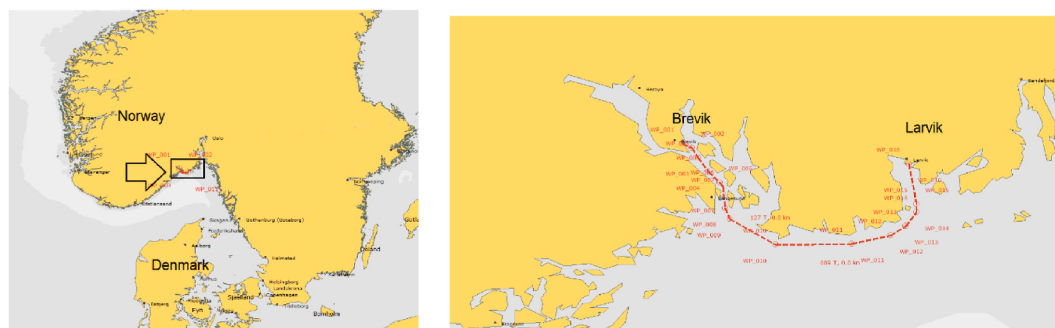


Fig. 2. The map of Norway (left); The pathway between Brevik and Larvik (Norway) for the navigation of autonomous 120-TEU container ship Yara Birkeland (right).



Fig. 3. First unmanned cargo ship made in China *Jin Dou Yun 0 Hao* off Zhuhai, Guangdong, Southern China during its first demonstration voyage in 2019. Source: CHINA DAILY [48].

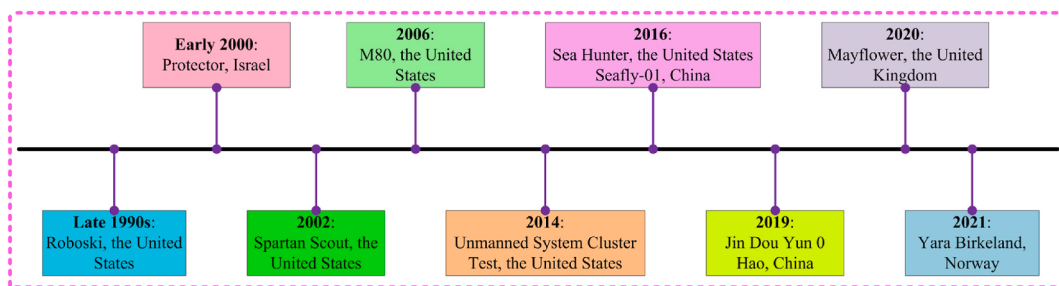


Fig. 4. A milestone map for the main achievements in the unmanned ship development.

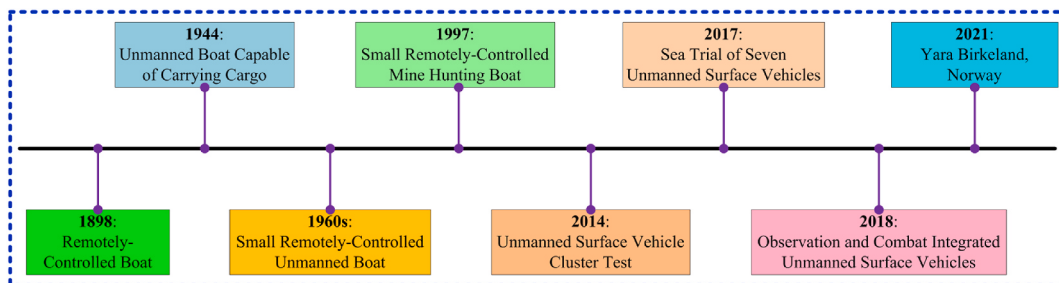


Fig. 5. The deployment timeline of the key technologies associated with the unmanned vessel research.

autonomous ship navigation research: (I) the majority of the current research has been largely supported by the relevant stakeholders who would favor the use of such technology; (II) most existing research studies fail to address the demand for the end user; and (III) the current research mainly highlights future prospects rather than providing potential solutions and recommendations for the existing challenges. Along with the key research questions outlined in the previous section, this article also seeks to address these three main challenges by conducting a series of interviews with relevant Chinese “implementation stakeholders” (i.e., shipyard managers, shipowners, ship operators, ship managers) and seafarers. Valuable feedback from these key groups of stakeholders is intended to be used to guide the future autonomous shipping research.

2. Methods

The data used in this study was mainly collected through a mixed method, including a series of comprehensive semi-structured interviews and online surveys, to evaluate the perspectives of stakeholders. The empirical data directly used in the present research was gathered by the corresponding author during two field research trips in China (2017–2018), where the following major research activities were completed: i) a web-based questionnaire survey and semi-structured interviews were conducted with the key stakeholders in the maritime sector, and ii) follow-up data gathering activities through common communication platforms (i.e., WeChat and QQ Talk) were carried out with the relevant representatives in China. A copy of the questionnaire that was used during the surveys and

interviews is provided in Appendix A.

Web-based surveys were conducted for data collection. They were comprised of 11 structured questions (see Appendix A), and were delivered through the WJX web-based survey platform. Purposive sampling was used to identify prospective respondents, and this was integrated with a snowball sampling method. In order to increase the number of responses, the authors mobilised their social networks to distribute “invitation to survey” messages via email, QQ talk, WeChat, and other communication platforms. Within four weeks of distributing the invitation, 225 responses were received. The SPSS software was used to perform a descriptive analysis of the quantitative data (see Fig. 6).

To gain a deeper understanding of the perspectives and opinions of the major stakeholders, several field trips were made to conduct semi-structured interviews. The field trips covered the major coastal port cities between the northern city of Dalian and the southern city of Guangzhou. The corresponding author has worked in the maritime industry for more than 20 years, including 8 years at sea, and this was imperative in gaining access to a large number of stakeholders in the maritime industry. Normally though, qualitative research does not necessarily require a significant amount of participants. Douglas [50], cited by Maykut and Morehouse [51], indicated that thorough interviews “with twenty-five people were necessary before the saturation point could be reached”.

Therefore, we performed 24 semi-structured interviews along with 32 informal conversational interviews. The semi-structured interviews were generally conducted either in hotels or offices. The average duration of semi-structured interviews comprised about 90 min. As for the conversational interviews, these interviews occurred informally in the field conditions, sometimes over lunch or coffee. Most of the semi-structured interviews were recorded, and brief notes or jottings were compiled in the course of conversational interviews. The participants were chosen from various categories of professionals in order to represent different perspectives (see Table 1). As a part of the “follow-up” activities, the WeChat group discussions were performed with a number of industry experts and relevant stakeholders. The information that was collected as a part of the interviews was utilized to gain a deeper insight and a thorough understanding of the responses contributed by the major stakeholders with respect to the development of China’s autonomous ships.

3. Findings

3.1. Attitudes of Chinese maritime stakeholders towards the unmanned ship deployment

Respondents were asked how much attention they devoted to the development of unmanned ships. Response options were: i) special attention, ii) general attention, iii) low attention, and iv) no interest. Over 78% of participants responded that they had given the topic special or general attention (see Fig. 7). Respondents from shipping companies, port operators, and government departments were more interested in the development of unmanned ships than others. Over 67% of respondents confirmed the importance of unmanned ship technology, and only 13% were familiar with relevant issues. As Fig. 8 shows, the respondents who devoted more attention to unmanned ships tended to be more familiar with the subject than others. The majority (77.3%) were optimistic about the future of unmanned ships. However, almost 60% of the respondents believed that unmanned ships would not be commercialised before the next 20 years (see Fig. 9).

Various obstacles are restraining the immediate adoption of unmanned vessels. Fig. 10 describes some of the major challenges facing the introduction of unmanned ships. These factors include: i) technology, ii) legal frameworks, iii) safety, iv) security, v) cost, and vi) humanity challenges. Shipping companies and port operators are the two key stakeholders which would be directly impacted by the unmanned vessel technology. During the interviews conducted with these stakeholders, they emphasised the technical, operational, and legal challenges. Over 60% of respondents from these two categories considered technological and legal issues as the two major challenges facing the commercialisation of unmanned vessels. A significant number of responding seafarers, manning

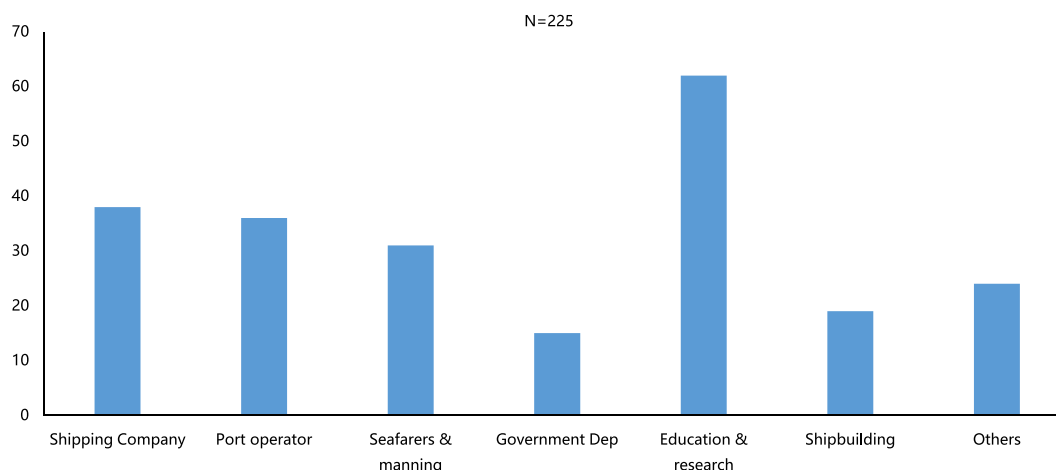
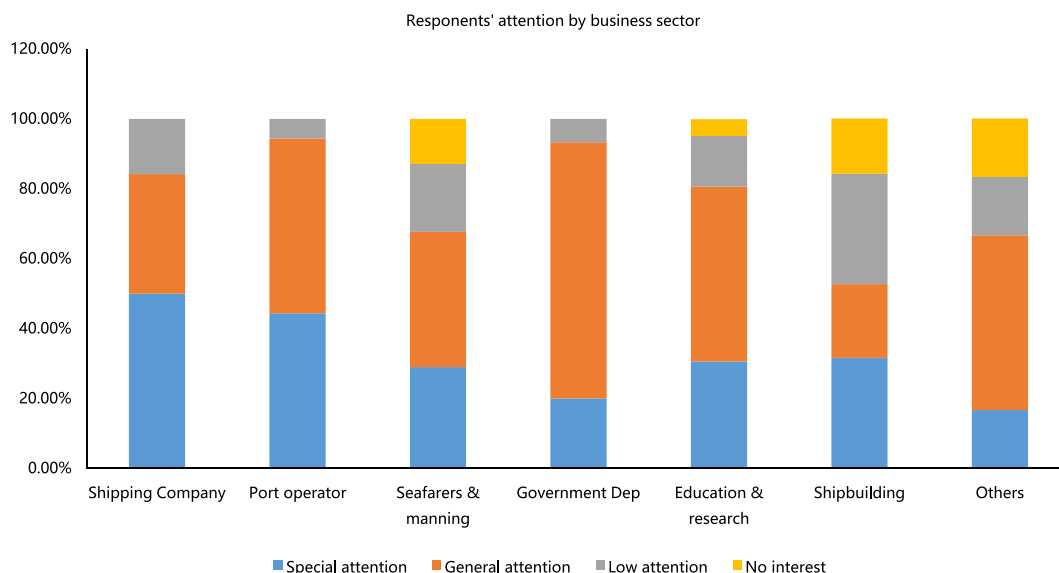
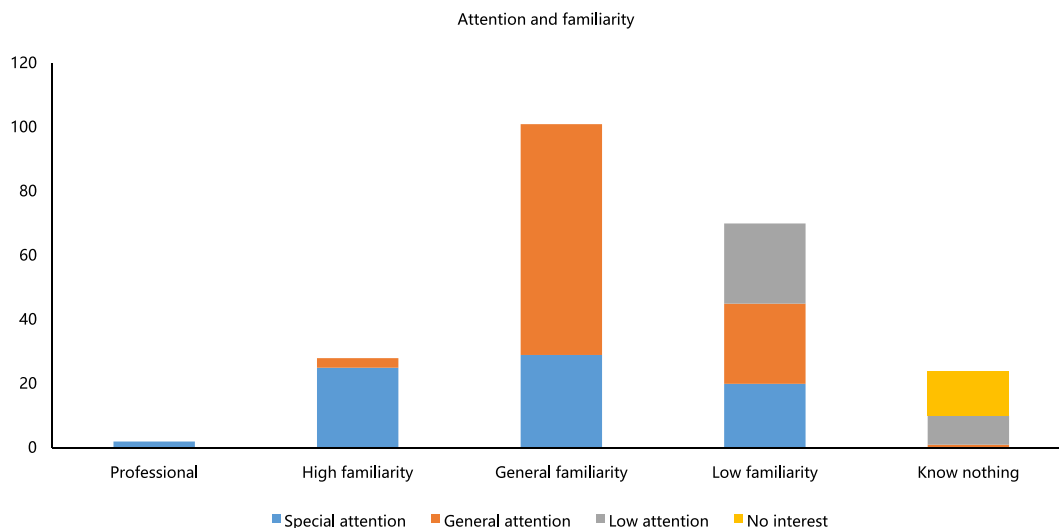


Fig. 6. Distribution of stakeholders by business sector.

Table 1

List of participants in semi-structured and conversational interviews.

Sector	Semi-structured interviews (N)	Conversational interviews (N)	Background of respondents
Shipping companies	5	7	Senior managers and claim managers
Port operators	4	5	Deputy directors, senior managers, and junior managers
Seafarers & manning companies	8	6	Manning agents, claim handlers
Government departments	3	5	Department heads, policy analysts
Education & Research	2	5	Maritime researchers and scholars
Shipbuilding companies	2	4	Design engineers, naval architects

**Fig. 7.** Respondent's attention by business sector.**Fig. 8.** Attention and familiarity of respondents.

companies, and government agencies considered the impact on seafarers and society as a major challenge. The implementation costs were generally considered to be a major challenge, but a limited proportion of shipping company respondents agreed on this point. The representatives from shipbuilding companies mostly underlined the challenges associated with the implementation costs. Implementation costs are considered as a common challenge associated not only with the deployment of autonomous ships, but also with the

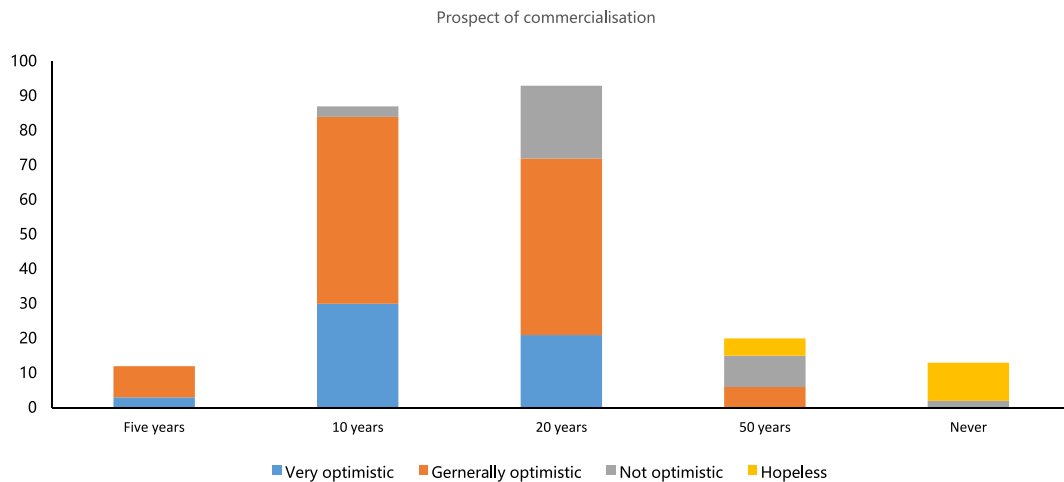


Fig. 9. Distribution of responses by the prospect of commercialisation.

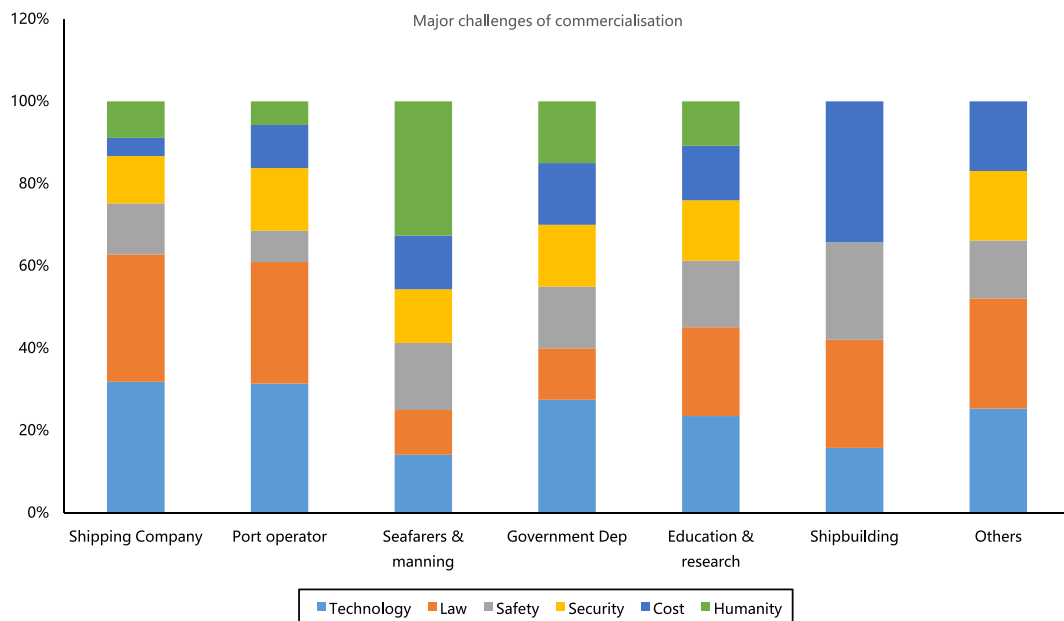


Fig. 10. Distribution of responses by the major challenges of commercialisation.

deployment of autonomous vehicles and trains [52,53].

3.2. Interconnection of system elements for unmanned vessels

The use of unmanned vessels relies on numerous factors pertaining to the satisfaction of particular requirements, the availability and production of needed technologies, defence industry engagement, government involvement, cost-benefit evaluation, safety at sea, employment and social factors. The key stakeholder viewpoints were considered in this study regardless whether the entity was a “user/buyer” (i.e., ship operators, seafarers, ship managers, and shipowners) or a “seller” (i.e., government agencies, software manufacturers, and shipyards). The responsibility of the sellers ends when the buyer has bought their product. Thus, the sellers incline toward using a “technological sales and marketing”-based method, while the buyers are more interested in operational and practical factors. Sellers affect decision-makers via a series of presentations at trade associations and the IMO and industry-funded studies. Various vendors are engaged in the building of components for every unmanned vessel. These components consist of radars, object and facial detection and identification software, sensors, Electronic Chart Display and Information System (ECDIS), high-speed computers, hardware, software, and communication technology, and motion-sensing cameras. Also, technicians are essential to give the necessary ongoing support. Additionally, classification societies may perhaps advance via government and industry-sponsored studies, and via

supplementary certifications and annual inspections. To demonstrate reliability, software and technology solutions require vigorous testing to assess their performance in real-life situations. As of 2021, there have been a few demonstration voyages, but there are no fully autonomous ships in active duty (see Table 2).

While it is assumed that autonomous ships will reduce the need for manpower in the shipping industry, their use may only transfer the need for manpower to shore-based workplaces. The use of unmanned ships will also involve niche companies that have exclusive rights to the key technologies and can provide high-level customer support, while the responsibility and liability of ships remain with the shipowner. This could potentially lead to complicated scenarios and new vulnerabilities for shipowners. One challenge is that unmanned autonomous vessels must be able to possess ship integrity and the integrity of its machinery (internal environment) and must interact continuously with the sea and the objects that are fixed and floating around it. This requires anti-collision assessments through continuous risk evaluation and mitigation, course alterations, collision avoidance manoeuvres, weather observation, and the establishment of communication with various entities, such as other ships, port control, and pilots (external environment). Humans will need to contribute to the development of these systems and will be necessary to create trust in the technologies. Doing this has been difficult for unmanned cars in a far less dynamic terrestrial environment. Unmanned ships attempt to operate through technology in three distinct domains: Sensor technology, Control algorithms, and Communication. All three domains have equal significance.

Sensor technology is now established and can be found in autonomous land vehicles, particularly in those where competition between creators is high. Due to the maritime environment being far more diverse than the terrestrial environment, ships are equipped with additional elements, such as thermal imaging, high-definition visual cameras, and diverse types of radars. For example, a 20-day passage from Shanghai to Rotterdam involves i) a temperature variation of about 50° Celsius, ii) weather changes from Beaufort force 1 to 8, iii) stormy spray-laden seas to calm placid waters, and iv) traffic varying between wooden 3-m long *bangkas* (wooden boats) in the China sea, fishing vessels that routinely fail to appear on the radar, and large ships. Anecdotal evidence suggests that unlit fishing boats, especially off the coasts of Sri Lanka and Africa, are due to the high expense of oil and electricity. It is common for marine-grade watertight electronics to spoil in alt-laden sea spray.

While the technology to address these substantial variations exists, it is exceptionally expensive and normally only used in highly critical operations, such as space exploration. The challenge is to figure out how these technologies can be combined to resolve various maritime environment challenges in the most cost-efficient way possible [42]. For example, collision avoidance requires certain measures, such as control algorithms, that link the navigation and collision avoidance systems on the vessel, radars, ECDIS, thermal imagery sensors, and supercomputers that calculate the closest point of approach (CPA) and the time to the closest point of approach (TCPA) for dozens of targets at a time. These systems alert the decision-making computer software, so the ship can respond appropriately. It is vital that the sensory information and the decision algorithms run perfectly, as they must comply with maritime rules and regulations and perform sufficiently in real-world scenarios.

Due to the highly expensive nature of ships and their cargoes, humans will still be involved in the operations of unmanned ships, albeit from a control station on land. For this to occur seamlessly, the shore-based crew and the vessel need to be linked through a high-speed data transfer system. Data must be conveyed internally, between sensors and computers, and externally to the shore-based monitoring station. Currently, maritime communication is still very expensive compared to terrestrial communication. In order to communicate efficiently with the vessel, the systems need to be able to handle a bidirectional dialogue between multiple systems at the same time and provide accurate information for actions to be based on. Once this is possible, there will be a comfortable level of redundancy, and the risk of accidents will be minimised [42].

Another important issue to keep in mind is the presence of different levels of autonomy in ships. Some are being developed to be

Table 2
Trail voyages (TV) of unmanned commercial ships in 2015–2020.

Trial voyages (TV) of unmanned ships:		
Vessel	Main entity/entities	Remarks
<i>Jin Dou Yun O Hao</i>	China Classification Society, Wuhan University of Technology, Zhuhai City government, Yunzhou-tech	Cargo capacity = 2 TEUs, Small craft L = 12.86 m, W = 3.8 m, d = 1 m, spd = 8 kts, sailed TV from Zhuhai to Shenzhen in 2019 carrying one TEU [48]
<i>Yara Birkeland</i>	Norway government, Kongsberg	Cargo capacity = 120 TEUs, customised for short (<8 h) coastal passage between 2 ports of Norway
<i>Mayflower autonomous ship</i> (see note 1)	UK government, Rolls Royce	Research ship (nil cargo capacity) [54]
(see note 1)	Rolls-Royce plc	Ferry, operated in a remote-controlled mode for TV between Parainen and Nauvo (Finland) with standby personnel on board
(see note 1)	Wartsila Marine Business	Offshore vessel retrofitted for TV off Aberdeen (Scotland), remotely controlled from San Diego (USA) in 2017
<i>Folgefohn</i> (hybrid car carrier)	(see note 1)	TV docking and undocking in 2018

Note 1:

These test voyages were short-duration voyages, after which the ships reverted back to the conventional manned mode. Details and specifics of these ships were not found in the public domain.

Autonomous “test ships” under construction/completed:

- *Mayflower autonomous ship* (Wartsila intellitug using RS24 sensors)
- *Yara Birkeland* (a joint project between Yara, Kongsberg, Marin Teknikk, and the Norwegian government to transport chemicals from the Yara’s Porsgrunn factory to Brevik by truck, then from Brevik to Larvik by ship) [55]

“self-navigating” without any human inputs at all, while others aim for automated navigation with humans monitoring either on board or ashore [56]. The latter is a risk mitigation method to protect multimillion-dollar ships and their cargo, which could have a value that is several times higher. The following are examples of autonomous ships:

- Smart vessels – manned vessels that have a relatively high level of automation;
- Hybrid solutions, where unmanned vessels and/or remotely operated vessels are guided in a convoy by a manned vessel;
- Short-manned vessels, where the operations under manned supervision last for 12 h followed by 12 h of supervision from a control center located onshore;
- Unmanned vessels that are generally operated in a remote fashion from a control center located onshore;
- Vessels that are classified as fully autonomous.

Regarding regulations, the vague definition of the term “ship” in international and domestic legislation has brought some uncertainties as to whether unmanned ships would fit into this category or not. In the marine environment, a ship is generally recognized to be large watercraft that delivers cargo and people travelling along the waterway. Nevertheless, in the legal principle, there is no standard explanation for the term “ship” and it has been claimed that there is a low expectation of one being promoted because of the wide variety of kinds of ships [57]. According to the International Labour Organization (ILO) Conventions and IMO, the terminology has been provided with various explanations which change remarkably relying on the area in which the ship is navigating or located, the kind of functions that it performs, and the volume of people delivered, to name a few. As an example, remotely operated vehicles (ROVs) are regularly employed in underwater operations for research ships to explore gas and oil locations. This particular type of vehicle is often connected to a mother ship with an “umbilical cord”. It can also navigate on the surface and be mobile-operated.

In case of a collision, will the ROV be recognized as a ship? What are the particular regulations that can be used in this situation? The aforementioned questions still remain unanswered. However, there are specific crucial features that interpret a ship, including buoyancy, operating in international waters rather than river navigation or inland water, the capacity of carriage of cargoes and people (whatever they are transporting at a point in time), and the capacity of controlled motion on water [58]. In accordance with the framework, unmanned functionality may not explain to a full extent unmanned skills of their position as “vessels” or “ships” under the existing maritime regulatory framework [59]. The existing IMO legislation concerning MASS is relatively limited, as they are still extensively monitored in coastal waters and are immature.

The future legal frameworks will impact the development of unmanned ships and could affect global trade. Flag states, classification societies, and insurance companies will have significant tasks ahead of them. For that reason, in December 2018, the MSC initiated a regulatory scoping exercise (RSE) and assessed several IMO instruments (e.g., SOLAS, collision regulations, ship loading, and stability) for applicability to autonomous shipping. In June 2019, the IMO MSC held its 101th session and discussed a status report on the RSE, which was expected to be completed in 2020 but was extended due to COVID-19 [60]. The purpose of the RSE is to identify how MASS could be approached using the IMO instruments by means of reviewing the current requirements and preparing a roadmap as to how the current IMO instruments can be adapted to further integrate MASS in the future. The RSE defines four degrees of automation, however, they are too simplistic, as each unmanned vessel is different [12]. Additionally, during the IMO’s 101th MSC meeting, a set of interim guidelines for the conduct of autonomous ship trials was presented. Currently, under development, these high-level goal-based guidelines are expected to be a single document to guide administrations, the industry, and other relevant stakeholders when it comes to the matters related to unmanned and autonomous ships [61].

3.3. Main advantages of unmanned vessels

Any debate on the commercial benefits of MASS must compare them to the conventional ships of equal size, trade, cargo, and sea area of operation. One must show that (a) MASS can be operated equally well with reduced costs, and (b) that MASS are as safe, resilient, and flexible as conventional ships. Crewing is one of the many significant expenses for shipowners, accounting for about 5–15% of the ship operating expenses depending on the nationality of the crew. The main advantage of MASS hinges on the decrease or removal of the crew. Decreasing expenses in crew-relevant costs stem from different elements, including crew sign-off, joining, educational activities, ship agency costs, extensive training costs, and crew salaries (see Table 3 and Table 4).

All these reductions in costs are particularly favorable in case of the automation and machinery operating along with a smaller-size crew in its place. Despite this has been exhibited by MASS supporters adopting future forecasts and models, it is challenging to understand the nature of these crew-related expenses with the exception of controlled experiments that differentiate a traditional vessel

Table 3

Purported benefits of unmanned ships. Source: Research carried out during this study.

Purported benefits of unmanned ships:

- Lower crew manning and crew-associated costs
- Lesser chances of crew errors
- Avoidance of issues arising from crew fatigue and related navigation and machinery errors
- Reduction of accommodation space = increase in cargo carriage space
- Control and monitoring from ashore

Table 4

Comparison of crew-related expenses and additional expenses for autonomous unmanned ship operations. Source: Interviews conducted as a part of this study.

Crew-related expenses	Additional expenses for outfitting an unmanned/autonomous ship (MASS)
Ashore:	Outfitting:
• Manning agency costs in the country of crew domicile • Pre-joining medicals and formalities • Certification and equivalent Certificate of Receipt of Application from the flag state • Airfare to/from the ship for crew sign-on/sign-off • Local agent fees at the sign-on/off port • Training (classroom, online, cognitive behavioral therapy (CBT)) • Insurance (Protection and Indemnity)	• Various equipment costs (vendor and equipment dependent) including - Sophisticated high-resolution water and heavy weather-resistant equipment and cameras with motion sensors and object identifiers - Sophisticated software for above - Sophisticated computers for above - Interfacing software - Decision-making software • Manpower for installation • Class attendance
On board:	Operational:
• Wages (onboard + standby + allowances) (rank dependent) • Victualling/food (normally US \$ 7–10 per head per day)	• Customer support • Maintenance of MASS equipment • Replacement and spare parts

from a mother vessel supplied with unmanned automation systems. Although the operational costs are expected to decrease due to the crew size reduction or complete elimination for unmanned ships, there are some other costs associated with their operations that have to be accounted for. Table 4 provides more details regarding crew-related expenses and additional expenses for autonomous unmanned ship operations, which were identified as a result of the interviews conducted throughout this study.

Shipowners could also benefit from savings on liability insurance since the crew would face less hazardous work conditions while being placed in shore-based workplaces. As a senior manager of ship management in Shanghai commented in 2018:

“The crew wage bills are certainly a primary motivation for shipowners who intend to invest in unmanned ships. The benefit also extends to reduced training costs, insurance, death and injury compensations, medical care, food and catering, daily utility, and so on. The savings on this could be large and attractive for many shipowners.”

In addition, the areas generally arranged for storage can be reserved for additional space for cargo, which is likely to boost the revenue of shipowners accordingly. Concerning the safety of life at sea, the codes and IMO conventions manage the safety of operations, the supplies on board, and the building of ships. Numerous standards increase shipowners' costs due to taking into consideration the humans on board (e.g., shipowners are obliged to provide and sustain fire-fighting and life-saving facilities on board). Unmanned ships would be possibly built and operated at a decreased cost and could lift certain limitations concerning cargo volumes and others in case there are no people on board.

The shipping industry is a “human-concentrated industry” and human errors, particularly seafarers' errors, are quite frequently the main cause that leads to casualty situations [62]. It is estimated that over 75% of marine casualties are caused primarily by human errors [63]. As Apostol-Mates and Barbu [64] stated, the human element has contributed to 79% of towing vessel groundings, 84–88% of tanker accidents, and 89–96% of ship collisions, and the figures are similar in all kinds of casualty situations. Accidents are not normally triggered just by failure or mistake, but by a series of mistakes either made by one person or due to a lack of reaction by other human personnel involved [65].

In critical times, when the human elements should interfere, the omission, misconduct, and underestimation of hazardous situations are described as human errors, and the results might lead to a casualty situation [66]. The main causes of human errors have been attributed to the factors, such as fatigue, communication and training problems, inadequate general technical knowledge, and the environment on board. It has been observed that these factors can have a significant impact on how seafarers react or perform different types of shipping operations. A study comparing the safety of unmanned ships versus conventional ships revealed that the likelihood of navigation-related accidents, such as collision or grounding, would be greatly reduced on an unmanned vessel, especially in the events when human actions could have a direct impact on the occurrence of these accidents [23].

Furthermore, the use of unmanned ships could resolve long-standing security issues, such as hijacking, piracy, and stowaway. These issues could frustrate the commercial venture and lead to large financial losses, legal consequences, and substantial interventions into normal operations. Most hijacking and piracy occurrences are associated with the payment of ransom. No crew members on board means that the hijacking risk could be disregarded. Even if a vessel is seized by pirates, armed forces can easily retake the vessel if there is no risk of endangering the crew. It has also been theorised that when there is no accommodation space for people to live or hide in, stowaway is unlikely to happen. When seafarers are removed from the ship, high-voltage fittings on the ship structure could also be used to prevent unauthorised people from getting on board.

Slow steaming shipping (SSS) is an additional advantage of the unmanned vessels. SSS is a process of significantly reducing the speed of ships to cut down fuel consumption and carbon emissions [67–69]. Research shows that reducing ship speeds by 10%–20%

will lower greenhouse gas emissions by as much as 13% [70]. Thus, it is a common operating feature of today's shipping market and a way to lower costs by reducing fuel consumption. However, in practice, the planning may often be overridden by the shipmaster when there is no motivation for the crew on board. Also, if the ship is on time chartering, the shipowner may not strictly adopt the practice. As a marine master explained in an interview in 2018:

"Yes! We have often been required to adopt slow steaming shipping, and I follow this requirement from time to time, but not all the time. I understand that there is an economic benefit for the owner and charterer, but many times the crew just has no motivation to do that. Frankly speaking, sometimes I prefer to go faster and then stop somewhere occasionally, or to arrive early and wait in the anchorage in case the ship misses the laycan. In particular, no one wants to move slowly in good weather and then have to encounter poor visibility or even a storm."

When there are people on board, there is uncertainty about the implementation of SSS. If the ship is on a time charter, even the shipowner may not care about the bunkering bills. As charterers, they are unable to monitor the execution of SSS. Noon reports and daily bunkering consumption are the only methods to know the ship's movement, but all these can be easily manipulated by the crew. Regarding SSS, unmanned ships certainly have advantages over conventional ships. There would not be anyone on board to override the planned route and speed, and there is normally no conflicting interest between the shipowner and charterer in this respect.

Certainly, unmanned ships are more beneficial in terms of environmental pollution prevention and compliance with the MARPOL regulations due to the potential use of SSS and the use of newer and better engine designs with more efficient emission control of NOx [71]. The environmental impact of shipping includes air pollution, water pollution, acoustic pollution, garbage, and oil pollution. Marine environmental regulations have become increasingly strict in recent years. Unmanned ships will reduce the impact of shipping and render it easier to comply with the regulations. There would not be any requirement for refrigerated rooms for food storage or accommodation of air circulation systems. At the same time, the dumping of garbage, oil, sewage, and toxic materials will be also eliminated [72].

4. Major challenges and future prospects

Autonomous shipping remains a controversial topic among shipowners, charterers, operators, ship managers, engineers, and seafarers. The following nine barriers to the adoption of unmanned ships were identified during our research: i) highly dynamic maritime work and environment which necessitates high levels of ever-changing multi-tasking, continuous risk assessment, and decision making, ii) high dependence on artificial intelligence and automation in currently proposed MASS solutions, iii) high degree of expensive third-party shore support necessary for operating unmanned ships, iv) absence of practical demonstration in day-to-day circumstances, v) high costs associated with these factors, vi) limited vendors for autonomous shipping technologies making it a niche proprietary technology, out of the realm of markets, vii) low levels of accountability and liability in case of stoppage, collision, or cargo issues, viii) continued necessity of manning the ship for arrival at ports and departure from ports, and ix) current compatibility issues between various shipboard equipment units and autonomous computer shipping software.

The production of autonomous ships requires the installation of specific equipment that commits a shipowner and excludes the possibility of reverting back to a conventional ship. Interviews with ship staff who have sailed on ships that experimented with autonomous shipping technologies for certain capabilities narrated a number of issues related to excessive alarms and poor course keeping due to excessive course alterations by the software. These issues led to higher fuel consumption, lower speeds, and problems with reliability and performance due to the inability of equipment to withstand the level of vibrations and bad weather. The above factors have influenced a general consensus among shipowners to adopt a "wait and watch" approach for unmanned ships. Humans can be interrogated and guided from ashore and can be held accountable. Autonomous machinery could only be manipulated by specialized vendors who are based in Europe and, hence, cost far more than the current system.

Currently, under international and domestic maritime laws, in cases involving a collision, especially the ones that involve fatalities, the personnel found to be responsible for the incorrect navigation are usually blamed for the accident, through the evidence provided by lawyers and a panel of judges. The costs of repairs are recovered through insurance, namely the Marine Hull and Machinery (H&M) insurance and the Protection and Indemnity (P&I) insurance, through various liability clauses inserted in the maritime charter parties. Currently, none of the unmanned ship technology providers accept any of these responsibilities. Hence, it could be argued that

Table 5

Definite and hidden costs of unmanned ship operations. Source: Interviews conducted in this study.

Definite costs:	Potential hidden costs:
• Installation costs • Subscriptions • Customer support • Maintenance – time and costs • Spares • Software upgrades • Annual maintenance contracts • Shore support manpower • Training of shipowners, operators, and managers	• Troubleshooting • Increased insurance • Attendance by trained OEM (original equipment manufacturer) or service technicians and airfare • Legal costs • Increased risk – navigation • Crew joining, salary, and sign-off if the crew is hired to oversee unmanned ship operations or for the arrival/departure at/from ports

unmanned ships shift the outfitting costs, risks, responsibility, and liability to the shipowner. In this respect, there seems to be a little benefit for the shipowner to take such a risk. Furthermore, the crew would have to be hired to bring the ship into the port. This would increase logistics costs in case of container ships (which tend to visit a new port every few days), general cargo ships, bulk carriers, and tankers on tramping runs, where it is normal for the next port to change. Plus, stationing local officers at each port might well increase crew manning costs. More insights regarding definite and hidden costs of unmanned ship operations, which were identified as a part of the conducted interviews, are presented in Table 5.

Moreover, even if an unmanned ship is able to perform the functions of humans, such as deck and engineer officers, it might be practical and affordable only at certain parts of the world, on certain ships, and on certain runs in certain waters. They would still require additional manpower ashore. Current maritime communication technology is expensive and still has its limitations. During the interviews, all officers spoke of at least a few occasions each year when they had issues sending and receiving email messages and data due to satellite and software issues. This is also common at ports with large gantry cranes due to blocking of the lines of sight. The high dependence of unmanned ships on data transfer thus leaves these ships highly vulnerable.

Further, unmanned ships are more vulnerable to cyber-attacks than conventional ships due to a high level of guidance provided by different computer programs and software. This could increase insurance costs and could also increase cyber-security costs on a running basis for unmanned ships. In addition to the costs noted above, ship surveying and inspection, certification, maintenance, and repair would all contribute to the expenses of operating an unmanned ship [73].

Before large-scale adoption, the overall expenses of unmanned ships could deter a shipowner from their investments into unmanned ships. China is the largest shipbuilding country in the world. The prospect of unmanned ships has always been a hotly debated topic in the Chinese shipbuilding industry. According to the results of the questionnaire survey, while the respondents from shipyards reported that technology is the least one of their concerns, the cost is listed as the top major challenge. A senior manager in a state-owned shipyard commented in an interview in September 2018:

“There is no doubt that we can build unmanned ships, but the costs will be very high. Everything has to be specially customised, including design, processes, equipment, tests, control systems, and so many other elements. Theoretically possible, but practically very difficult. It is more than just building the hull and structure. The core issues are the controlling systems.”

In the meantime, it might be too optimistic to expect that unmanned ships will be safer than conventional ships. There is no doubt that seafarer errors will be eliminated, but human errors will continue to exist in the process of ship design and ship operation from a remote location. Even a fully autonomous ship needs supervision and intervention by people from shore-based control centers (SCC). As such, human errors can occur at any stage when there is an interaction between the ship and humans. Furthermore, situational awareness is crucial for the safe operation of the ship, as it is a major factor contributing to maritime accidents caused by human errors [74]. It is doubtful that the people located in an SCC would have the situational awareness needed to make a thorough decision in an emergency situation. Unmanned ships will lead to a lack of the experience and knowledge that seafarers used to gain during their time at sea [75]. There are concerns that, in the long run, maritime expertise will decline with the decreasing demand for onboard seafarers. The director of maritime education and training commented in an interview in 2018:

“A vigorous shipping milieu stands behind the maritime sector and consists of a large group of well-trained professionals in different areas. Many seafarers take a job ashore after their career at sea. It is very important to maintain a pool of experts with extensive seafaring experience and skills. Unmanned ships certainly have a negative impact on the performance of this pool. We will be losing the number of seafarers, naval architects, and engineers who are certainly needed for the development and operation of any merchant vessels.”

It has been argued that even if the likelihood of navigation-related accidents, such as collision or grounding, is greatly reduced on an autonomous vessel, the consequence of any other maritime accident could be of a greater magnitude on an unmanned vessel [23]. Maritime accidents of unmanned ships could result from a wide range of factors, such as faulty design, system failure, collision, cyber-security, cargo-related accidents, and so on. Seafarers with good seamanship on board can play an important role in rectifying and providing an effective response to a dangerous situation. When there are no people on board, dangerous situations could deteriorate even further due to ineffective responses from the shore-based operators.

If unmanned ships are to begin operating, a regulatory regime will have to be developed or the current one will have to be modified accordingly. Veal [59] proposed that the current main legal framework can be interpreted in a way that allows the inclusion of unmanned vessels into the current framework, and that this can be considered as the easier way ahead. However, before this can be achieved, a wide range of challenges and obstacles need to be resolved. The maritime industry is inherently international and also inextricably linked to various stakeholders with conflicting interests. As the adage goes, “standards are like toothbrushes, everyone agrees you should have one but no one wants to use yours”. For any new and disruptive technology, it will be difficult for the involved parties to put aside their differences and come up with a set of useable industry standards [76]. As a law professor at a maritime university commented in an interview in 2019:

“The maritime regulatory landscape is currently governed under a complex international framework. The regulations related to unmanned ships involve a large variety of different stakeholders, including shipowners, charterers, port operators, cargo and ship insurers, P&I clubs, shipyards, and so on. Many maritime terms and legal principles will be redefined, such as the law of seaworthiness, general average, cargo damage, ship collision, and salvage. While overcoming the current obstacles is not insuperable in the long run, it is doubtful that the restructuring of the maritime regulatory framework can be achieved in the near future.”

The introduction of unmanned ships creates uncertainty for many parties, including shipowners. For example, navigation and interaction with conventional ships, especially in high traffic density, is still a significant obstacle to overcome. The transition to the use of unmanned vessels will only be possible when all of these practical elements of ship operations are clarified [77]. As far as the commercialisation prospect is concerned, as shown in Fig. 9, very few respondents indicated that unmanned ships could be commercialised in the next five years. The vast majority of respondents believed that it would take 10–20 years at the minimum to realise the commercialisation of unmanned ships. In general, Chinese respondents confirmed the commercial benefits of unmanned ships and expressed optimistic opinions towards their commercialisation. As a director of a maritime consulting company in Shanghai commented in an interview in 2019:

“I do believe that unmanned ships represent an unavoidable future considering their commercial benefits. However, it might be over-optimistic to presume that a full automation mode suits for all types of ships or cargo or all shipping routes. In the beginning, it might be more realistic to start with some specified grades of cargo with certain types of ships on localised short-sea shipping routes.”

5. Conclusion and recommendations

The popularity of unmanned ships increases every year in different countries across the globe, including China. Unmanned ships are expected to change the maritime industry. However, there is a lack of relevant studies explicitly focusing on a deep understanding of potential advantages and challenges associated with the deployment of unmanned vessels in China, integration of industry 4.0 in the maritime industry, and integration of industry 4.0 with unmanned ships specifically. Therefore, this study investigated how Chinese stakeholders have reacted to the emergence of Maritime Autonomous Surface Ships (MASS) and associated technologies that would be required for their operations and how MASS would influence the global maritime world.

MASS supporters have perceived the decrease in the ship crew size or complete ship crew elimination as a favorable feature mainly due to reduction in the operational costs. But industry professionals expressed their opposite viewpoints on this manner. Although a small number of “demonstration voyages” that involve unmanned ships have been conducted to date, there are numerous unsettled matters that do not induce enough confidence and trust in the state-of-the-art technology used on fully unmanned ships. Such unsettled matters contain those associated with the high costs of MASS operation and outfitting, unsettled regulations, adaptability, credibility, and operational safety. As per the opinions of Chinese stakeholders, the major disadvantages of unmanned ships include the socio-economic impacts of unemployment, safety issues, captive technology, hidden costs of unmanned ship operations and troubleshooting, equipment costs, and poor cargo care with respect to current human-manned ships.

To increase suitability, the relevant stakeholders, who are interested in the deployment of unmanned vessels, need to adjust their attention from decreasing manpower onboard to minimizing the responsibility of seafarers on the vessels that are currently deployed on various shipping routes. This could assist with the identification of the actual reasons for fatigue on board and increase reliability. As such, manufacturers of MASS technology are obliged to obtain valuable feedback from the end users, notably ship operators, shipowners, and seafarers, as well as enhance their technology directly considering preferences of the relevant stakeholders. Also, the government may be more proactive and arrange financial subsidies into the development and deployment of unmanned ships and required technologies. To a certain extent, there is an urgent need for such technologies to be commonly adopted worldwide rather than only focusing on the Northern European region. The credibility of MASS technology requires substantial improvements worldwide. After the aforementioned issues that surround unmanned ships are successfully addressed and the proposed recommendations are adequately implemented, there is a potential for MASS to eventually become a sole solution to the existing fatigue-relevant accidents in the maritime industry and pave the ground for a new era in the maritime industry, the era of fully autonomous unmanned ships.

Although some valuable findings were discovered as a part of this study, there are certain aspects that could further receive more attention in the future studies. Firstly, the self-reported data related to the attitude and perception of different stakeholders towards unmanned ships may be biased by the willingness of stakeholders to provide an accurate answer. The target respondents may not be willing to report the actual information because of a shortage of unmanned ship knowledge, a chance of dealing with a lawsuit against them by the government, or individual repercussions. Secondly, this study mainly focused on China as a target study area. To generalize the research study, the future research efforts may consider conducting a regional study in Asia, including Japan, South Korea, Taiwan, Singapore, and Vietnam. Thirdly, the success of unmanned ships may rely on artificial intelligence, deep learning, and machine learning. The future research could put more emphasis on the state-of-the-art technologies that would facilitate the development and deployment of unmanned ships. Last but not least, this study primarily concentrated on identifying the main advantages and challenges associated with the development and deployment of unmanned ships. The future studies could further investigate specific achievements in unmanned vessel research in China and relevant patterns.

Author contribution statement

Qiong Chen & Pengfei Zhang: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper. Yui-yip Lau: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper. Maxim A. Dulebenets; Ning Wang & Tian-ni Wang: Analyzed and interpreted the data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interest's statement

The authors declare no conflict of interest.

Appendix A. Questionnaire on the development and application prospects of autonomous ships/unmanned ships in maritime transportation and shipping

Dear fellow experts,

Our research group is conducting a study on the development and application prospects of autonomous ships/unmanned ships in maritime transportation and shipping. We would like to know your valuable opinions. Your feedback will provide important insights for this study. There are only 11 questions in this questionnaire, and it may only take a few minutes to think carefully and answer all the questions. Thank you very much for your assistance with this important research activity.

1. Which of the following is your industry?

- | | | |
|---|--|---|
| ☐ Shipping companies | ☐ Shipbuilding companies | ☐ Seafarers & manning companies |
| ☐ Government departments | ☐ Education & research | ☐ Port operators |
| ☐ Others (please specify) | | |

2. How concerned is your organization with autonomous/unmanned ships?

- | | | | |
|---|---|--|--------------------------------------|
| ☐ Extremely Concerned | ☐ Generally Concerned | ☐ Occasionally Concerned | ☐ Not Interested |
|---|---|--|--------------------------------------|

3. How well do you personally know about the development of autonomous/unmanned ships?

- | | | | |
|---|-------------------------------------|---|--|
| ☐ Professional | ☐ Very familiar | ☐ Basic understanding | ☐ Slight understanding |
| ☐ I don't understand at all | | | |

4. How important do you think the development of autonomous/unmanned ships is in shipping?

- | | | | |
|--------------------------------------|--|-------------------------------------|--|
| ☐ Very important | ☐ Moderately important | ☐ Not important | ☐ Difficult to say |
|--------------------------------------|--|-------------------------------------|--|

5. Do you think the application value of autonomous ships/unmanned ships in shipping is underestimated (exaggerated)?

◦ Seriously underestimated	◦ Moderately underestimated	◦ Moderately overstated	◦ Seriously overstated
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6. What do you think of the current application scope of intelligent technology in marine ships?

◦ No application at all	◦ Very rudimentary	◦ Preliminary application	◦ Extensive application
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7. What do you think of the application prospects of autonomous ships/unmanned ships in shipping in the future?

◦ Very optimistic	◦ Moderately optimistic	◦ Not optimistic	◦ Very pessimistic
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8. How soon do you think autonomous ships/unmanned ships will be widely used in shipping?

◦ 5 years or so	◦ 10 years or so	◦ 20 years or so	◦ 50 years or more
◦ Impossible to achieve			

9. How difficult do you think the promotion and application of autonomous ships/unmanned ships in shipping is?

◦ Very difficult	◦ Moderately difficult	◦ Not too difficult	◦ Quite easy
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10. What do you think are the main obstacles to the development of autonomous ships/unmanned ships in shipping (multiple choices)? [Multiple choice]

☐ Technical obstacles	☐ Legal obstacles	☐ Customary obstacles
☐ Ideological barriers	☐ Cost barriers	☐ Other barriers (please specify)

11. Do you have any other points to add? Thank you

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