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# Barriers impending introduction of autonomous vessels

**Jan Pawelski**

https://orcid.org/0000-0002-9846-8765

Maritime University of Gdynia, Faculty of Navigation
3 Jana Pawła II Ave., 81-345 Gdynia, Poland
e-mail: j.pawelski@wn.umg.edu.pl

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**Abstract**

Today's shipping industry is experiencing a shortage of properly trained and competent deck and engine officers. This problem is becoming more acute with each passing year and traditional methods to resolve it apparently do not work. It has become obvious that cargo vessels must be less dependent on human operators. The solution lies in the replacement of manned vessels with autonomous ones. The introduction of autonomous vessels encounters several barriers, which need to be analyzed to find ways to overcome them. It requires a multipronged analysis of existing regulations, technical limitations, cyber security, and co-existence of manned and unmanned vessels in waters with dense traffic. The most difficult problems lie in international regulations, which were written for manned vessels only. Such rules need to be reworked before the deployment of autonomous vessels can be sanctioned worldwide. Technical issues are being gradually resolved with the introduction of new technologies. Special attention should be given to the cyber security of autonomous shipping as it requires the transfer of very large amounts of data through wireless networks. Accommodation of manned and unmanned vessel traffic may require a new approach for ship routing to separate both kinds of traffic.

## Introduction

For a few years, several countries and organizations have conducted studies on the development of technologies important for autonomous vessels, as well as international regulations governing future vessels. The most well-known research programs were MUNIN programs (Maritime Unmanned Navigation through Intelligence in Networks) conducted in the European Union (MUNIN, 2022) to develop the concept of the autonomous vessel and the Yara Birkeland project (YARA, 2022). MUNIN was completed in 2016, and a lot of valuable insights were obtained related to technologies for autonomous vessels. Norwegian project Yara Birkeland brought to life the first zero-emission, fully autonomous vessel scheduled to be fully operational in 2022. She was officially christened on 29th April 2022. In Poland, in the years 2017–2020, a research project was carried out involving Autonomous Vessels with an Air Look (AVAL). The experimental parts of this project were conducted with the participation of The Foundation for Safety of Navigation and Environment Protection, owned by the foundation Shiphandling, Research and Training Centre in Iława, Poland (Ship Handling Centre, 2022).

Personal experience gained when working on the project AVAL helped to focus attention on the introduction of problems due to autonomous vessels. All these projects were aimed at research in the field of new technologies. Examination of regulatory issues was pioneered by Danish Maritime

Authorities with a thorough analysis of international and Danish law published in 2017 (Danish Maritime Authority, 2017). In the same year, IMO (International Maritime Organization) began its regulatory scoping exercise on Maritime Autonomous Surface Ships (MASS). The exercise was completed in 2021 (IMO, 2021), and it became the base for the preparation of the non-mandatory MASS Code to be introduced in 2024; it was followed up by a mandatory code in 2028 (IMO, 2022). Existing analyses only focus on regulatory problems, so a wider approach is necessary. Indication of problems laying ahead for autonomous vessels was given in the article "*Problemy rozwoju statków autonomicznych*" ("Problems of Development of Autonomous Vessels") (Zalewski, 2020) with similar conclusions. Years spent at sea as a master and offshore installation manager provided practical knowledge of the problems, which may delay the deployment of autonomous vessels on a mass scale. The provided analysis aims to determine the causes of the growing interest in autonomous ships and to find hindrances that may delay operation of such vessels.

## Primary factors fostering the development of autonomous vessels

Due to a growing world cargo fleet, a search for how to improve the safety of its operations and productivity has been undertaken for several years. One perspective method is to follow the path of automatization of operations in the form of autonomous vessels. Today, the shipping industry has three strong stimuli to develop and implement such vessels. The first aims to improve safety of navigation by a limitation or complete removal of human factor, which is considered as the predominant cause of shipping accidents. The second stimulus is purely commercial and comes down to the elimination of high crewing costs from the vessel's budget. The third reason for autonomous vessel operations is a continuously increasing shortage of competent crewmen, particularly deck and engine officers. Besides this, shipowners expect to achieve several gains, such as increased productivity and integration of their vessels with land-based automated transport systems. Designs of new types of vessels will consider more types of alternative fuels and increasingly efficient propulsion systems. Terminals designed specifically for autonomous vessels will simplify mooring and unmooring operations, which will optimize the cargo handling processes.

### Role of the human factor in shipping accidents

For the last decade, safety at sea has increased beyond any doubt. The amount of totally lost vessels dropped more than twofold. Statistics of the AGCS (Allianz Global Corporate & Specialty) have registered 127 total losses in 2012 and only 54 of them in 2021 (AGCS, 2022, p. 12). It is a positive trend showing the effectiveness of new safety regulations. However, not all catastrophic events like multiple casualties, environmental pollution, or substantial financial loss ended with vessel loss. In pursuit of better economics, the size of the vessels is continuously growing, which means maritime accidents are becoming more acute than before in all aspects. Several studies found human factor as crucial aspect of accidents at sea. Data provided by the EMSA (European Maritime Safety Agency) (EMSA, 2022, p. 38) points to 65.8% of maritime accidents being caused by human error. Earlier research conducted in Canada and Atlantic Europe attributed human factor as the cause of 80% of maritime accidents for 2012–2015 (Cordon, Mestre & Walliser, 2015). This study also provides the main constituents of accidents as human factor; the number of cases in the analyzed reports is shown in Figure 1.

Situation awareness is the highest position for accidents caused by human factor when broken down into its components. This also tops a list of "The Deadly Dozen" published by the UK MCA (UK Maritime and Coastguard Agency) (UK MCA, 2016). The UK maritime authorities have named 12 elements of human factor that are responsible for accidents. A loss of situation awareness means that humans can often lose the overall picture of a complex situation and make erroneous decisions leading to accidents. A second leading position for human factor is a breakdown in work practices due to not following procedures and taking shortcuts, which are frequent cases. The introduction of decision support systems, and a gradual move toward fully autonomous vessels, should cure these problems.

### High crewing costs

Shipping companies seldom publish information regarding their budgets since they are trade secrets. Available information is scarce but allows for a rough estimate of what part of the ship's budget constitutes the cost of hiring and supporting a crew. Several maritime research and intelligence agencies sell professional reports on world shipping, which

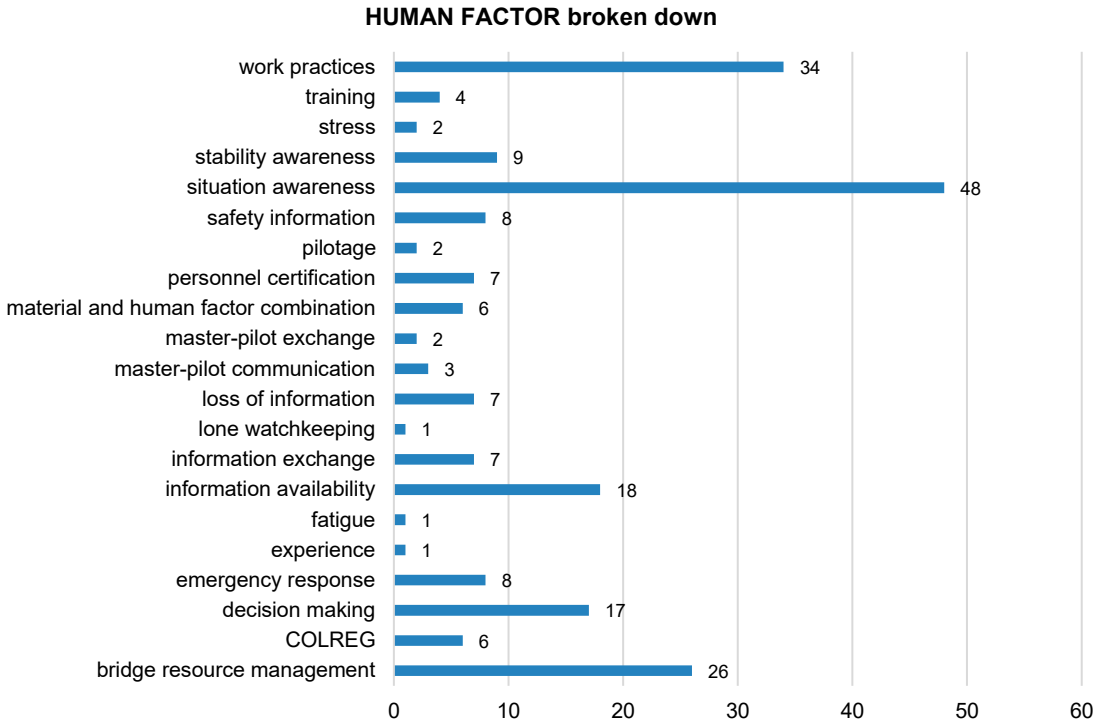


**Figure 1. Constituents of human factor in maritime accidents (Cordon, Mestre & Walliser, 2015)**

are used for maritime market analysis. Iconography from such a report is shown in Figure 2.

According to this information (Clarksons, 2017), the shipping industry spent almost 53% of its operating costs on wages and crew support in 2016 (before the COVID-19 outbreak). In 2019, the marine education and training platform Marine Insight published an analysis of the operational cost for the Handymax

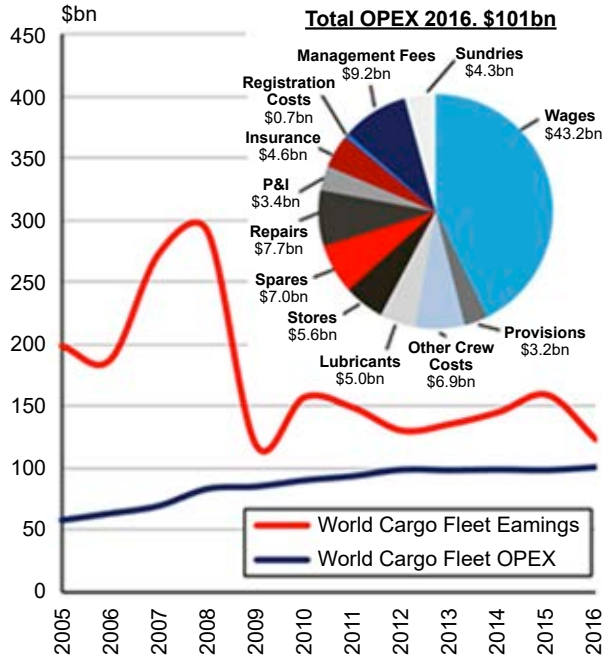


**Figure 2. Breakdown of the global cargo fleet operating costs (Clarksons, 2017)**

size bulk carrier, where crewing costs comprised almost 55% of the total running costs (Dsouza, 2019). During the COVID-19 outbreak, crew change costs sharply rose due to restrictions on personnel movement and the necessity of quarantine. Portal Seatrade-Maritime reported an expected rise in crewing costs by 10–15% due to the pandemic (Hand, 2020). Shipowners are expecting to make huge savings due to a partial reduction of the personnel onboard or elimination of the need for a crew at all.

### Competent crew shortage

In 2016, the Baltic and International Maritime Council (BIMCO) and the International Chamber of Shipping (ICS) published a forecast regarding the demands for seafarers in the incoming years (Safety4sea, 2018). A graphic presentation of this forecast is given in Figure 3.

It has been estimated that a shortfall of officers will reach 92,000 in 2020. The new BIMCO/ICS Seafarers Workforce Report was published in 2021 (ICS, 2021). This report provided corrected figures with a current shortage of officers amounting to 26,240, but nevertheless, it warned shipowners about a serious shortage looming in 2026. Shipping companies are now facing not only an increased rise in crewing costs, but also the prospects of increasing wages to attract more seafarers and reduce workforce turnover at the expense of their profits.

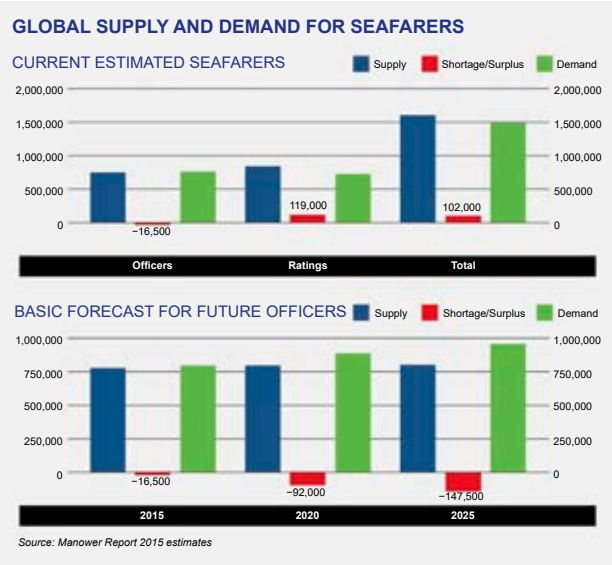


**Figure 3. A growing shortage of marine ratings and officers (Safety4sea, 2018)**

## Main barriers hindering the utilization of autonomous vessels

Moving towards autonomous vessels is widely perceived as the future of the shipping industry, but the use of such vessels needs to overcome several obstacles. The first type of problem is typically technical. Autonomous vessels require the adoption of several new and advanced technologies to make such ships remain as they currently operate. For the time being, the safety of the vessel is accomplished by the presence of the crew on board. The ship's systems responsible for navigation, propulsion, and cargo handling are built to be operated and supervised by humans. Depending on the degree of autonomy, such systems need to be re-designed for autonomous operations with human senses being replaced by an array of sensors. The rapid development of technology during the last decade enabled an assumption that all technologies needed to fulfill all the tasks of vessel safety are presently available. Growing demand for them further promotes their development and mass production. Shipowners are expecting that a reduction in the crewing expenses will offset an increased cost of new vessels. Taking all the above into consideration, it can be said that technology is not a significant obstacle in the way of the development of autonomous vessels.

More serious problems arise with the existing international and national regulations. All rules in force today were written for fully manned vessels. Many regulations require continuous control of vessels by certified crew members. The only viable solution to regulatory problems is amending and re-writing current international rules governing maritime shipping, as a basis for modifying national regulations. In 2017, the Danish Maritime Authority published a report analyzing the main regulatory barriers for autonomous vessels (Danish Maritime Authority, 2017) and identified their main categories, as shown in Figure 4.

The division of the regulatory barriers into seven categories sets a logical framework for the following analysis of each hindrance (identified earlier) for autonomous vessels.

### Jurisdictional issues

Articles 21, 22, and 25 of the United Nations Convention on the Law of the Sea (UNCLOS) granted coastal states several means to exercise their jurisdiction within territorial waters (UN, 1982).

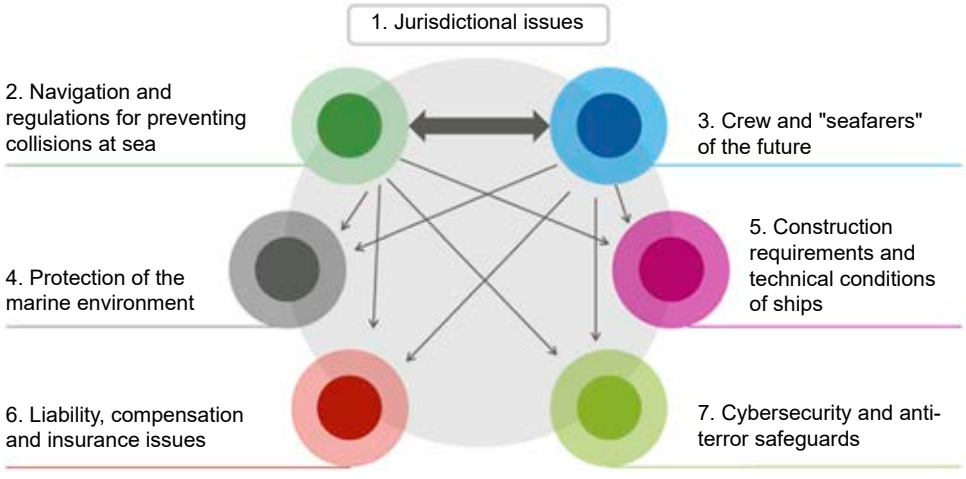


**Figure 4. Regulatory barriers (Danish Maritime Authority, 2017)**

States have the power to adopt laws to protect the safety of navigation, while also preventing accidents leading to environmental pollution or limiting movements to designated lanes. Today, most coastal states are members of several MOUs for regional cooperation that ensures better control of the compliance of ships with international regulations (IMO, 1991). Vessels not in compliance with international and local regulations can be denied the right of innocent passage, not only through the waters of a particular state but a group of coastal states cooperating in an MOU. It could be a severe setback for remotely controlled or fully autonomous vessels. The lack of a master, who acts on behalf of the vessel and shipowner, onboard an unmanned vessel also creates problems with local maritime authorities, customs authorities, and law representatives. For remotely controlled vessels, the coastal state may not agree to have the activity of foreign centers in their waters. Such problems can be resolved by providing some crew on board for certain legs of the voyage, providing a local representative for the vessel and, when necessary, transferring the remote control of the vessel to a local control center.

#### Navigation and regulations for preventing collisions at sea

Unmanned vessels cannot comply with current regulations of the Convention on International Regulations for Preventing Collision at Sea (COLREG), 1972 (IMO, 2017a), the International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers 1978, and the Seafarer's Training, Certification, and Watchkeeping Code (STCW 1978/95) (IMO, 2017d). Rule 5 of COLREG requires the maintenance of a continuous look-out by sight and hearing. The rules were written half a century ago; the only way to fulfill these requirements was to keep watch on the bridge all the time. For vessels with reduced crews, this rule can be interpreted with reference to the transmission from suitable sensors allowing the crew members to stay outside of the bridge and still comply with Rule 5. Remotely controlled and fully automated vessels cannot comply with this rule at the present time. STCW Convention and Code contain even more strict rules regarding watchkeeping on the bridge and in the engine room. Regulation VIII/2 of the STCW Convention requires the physical presence of a watchkeeping officer on the bridge at all times during his watch and an engineer to be physically available in the engine room when required. The same conditions of watchkeeping are repeated in the STCW Code in Section A-VIII Part 4-1. For the time being, autonomous vessels are tested within internal waters, where international rules are not applicable. Allowing such vessels to use the shipping lanes may lead to the collision with manned ships with crews not accustomed to their presence. Autonomous vessels operate within the constraints of their programs, and it is difficult to predict what action the crew may undertake. Separate lanes for manned and unmanned traffic could solve this problem, but there is not always sufficient space for it. Relaying control of an unmanned vessel to a local center may help to alleviate this situation.

#### Crew and the "seafarers" of the future

Regarding the manning of the vessels, UNCLOS Article 94 requires that "each ship is in charge of a master and officers who possess appropriate qualifications, in particular in seamanship, navigation, communications, and marine engineering" and "that the crew is appropriate in qualification and numbers for the type, size, machinery, and equipment of the ship" (UN, 1982). This rule can be extended for remotely controlled vessels with a person acting as a master ashore, but fully autonomous ships cannot comply with it. UNCLOS also calls for a master to render assistance to shipwrecked persons, which may be difficult for fully autonomous vessels without the development and introduction of new technologies, e.g., marine rescue drones.

#### Protection of the marine environment

Operations of autonomous vessels with reduced crew and unmanned is expected to limit environmental impact, due to the reduced discharge of garbage and sewage. Yet there remains an open question regarding the ability of unmanned vessels to cope with pollution from their own oil tanks and cargo. For the time being, there is no practical solution in the form of equipment capable of containing and cleaning up spillage without a crew. Without solving this problem, it might be difficult to prove that unmanned vessels represent the same level of environmental protection as their manned counterparts. The obligation to report incidents that may result in pollution also needs some attention. The International Convention for the Prevention of Pollution from Ships (MARPOL) (IMO, 2011) Protocol 1 Article 1 and the International Convention on Oil Pollution Preparedness, Response, and Co-operation (OPRC) (IMO, 1990) Article 4 OPRC requires, from

the master or person having charge of the vessel, to report on all pollution-related incidents. Manned and remotely controlled vessels can comply with both conventions, but fully autonomous vessels cannot.

#### Construction requirements and technical conditions of ships

Convention Safety of Life at Sea (SOLAS) (IMO, 2020) in Chapter I Regulation 4b anticipates the advent of vessels with new technologies and provides maritime authorities with exemption rights from the requirements of chapters II-1, II-2, III, and IV for vessels with new technologies engaged in international voyages. This has been done to facilitate research and development. This provision leaves much discretion to the flag state, but a lack of widely recognized standards for autonomous vessels may lead to the refusal of such vessels in some places under the pretext of unproven and potentially unsafe technology. Provisions in Chapter I Regulation 5a require that the flag state conducts extensive tests before approval of new technology, to prove that it is as safe as the technologies already in use. Some hindrances for autonomous vessels can also be found in Chapter II-2: Construction, fire protection, fire detection, and fire extinction and in Chapter III: Life-saving appliances and arrangements, where the rules stipulate the presence of a crew on board.

#### Liability, compensation, and insurance issues

Liability in the shipping industry is based on a competent, certified crew being in charge of the vessel. In case of accidents and subsequent damage, the shipowner is liable for the action of all the parties in his service, although the master and crew are also held accountable. Liability in the shipping industry is governed by the national legal systems in the flag states. For accidents in territorial waters or on the territory of the host country, local rules are applicable. It pertains directly to manned vessels with a full crew and decision support and vessels with a reduced crew. Unmanned vessels fall into two categories. The first involves remotely controlled vessels with an operator on shore, who makes all decisions in the same way as a crew on board a manned vessel. The second category is fully autonomous vessels making decisions by themselves. In the first case, besides the shipowner, liability is placed on the remote operator similar to the master of a manned vessel, most likely under his national jurisdiction. For fully autonomous vessels, liability lies solely on the shipowner (Danish Maritime Authority, 2017). It is unlikely to extend liability to programmers and manufacturers of ship's systems, but they are subject to national regulations. Information regarding the insurance of autonomous vessels is currently unavailable since no commercial autonomous vessels are in operation. The only existing autonomous vessels, like the Yara Birkeland, are generally built as test beds for the development of new technologies; they are not designed for international voyages (YARA, 2022). They have insurance coverage required by national regulations, but this is limited only to conducting tests.

#### Cybersecurity and anti-terror safeguards

Cybersecurity problems arose when the vessel began to utilize digital systems based on computer architecture. Autonomous vessels are particularly vulnerable to cyber threats, as they heavily rely upon complex computerized systems, large data transfer through satellite links, and satellite navigation. In 2017, IMO addressed the problem of cybersecurity for the first time in Resolution MSC.428(98) (IMO, 2017c), which encourages maritime administrations to address cyber risks in safety management systems. A month later, it was followed by an IMO circular MSC-FAL.1/Circ.3. (IMO, 2017b) with a list of identified shipborne systems vulnerable to cyberattacks and recommendations for cyber risk management. Up-to-date guidelines are published by the Baltic and International Maritime Council in "The Guidelines on Cyber Security Onboard Ships" version 4 (BIMCO, 2020). Today organized crime targets large shipping companies rather than single vessels. The four biggest shipping companies (APM Maersk, Mediterranean Shipping Company, COSCO, and CMA CGM) underwent cyberattacks from 2017 to extort ransom. Attacks interrupted their operations for days and even weeks (Cimpanu, 2020).

The operation of high-value autonomous vessels certainly will attract the attention of criminals. Regulatory anti-terror safeguards are provided by the SOLAS Convention (IMO, 2020) and the International Code for the Security of Ships and Port Facilities (ISPS Code) (IMO SPS, 2020). These regulations were written for manned vessels but some requirements, like the necessity to have security plans and alerts in case of a security threat, are still applicable. For unmanned vessels, more important are the technical safeguards like physically preventing access by unauthorized personnel

and effective surveillance systems. Satellite navigation systems should be protected against jamming and spoofing, in a similar way to military systems. Spoofing may result in a purposeful deviation of a vessel from its intended route with bad intentions. The jamming of the navigational satellite signal is a relatively easy task that requires simple means. Without navigational information, the vessels cannot continue their voyage. Unmanned vessels controlled from the shore and fully autonomous vessels that are remotely controlled, when required, depend solely on the exchange of large amounts of information via a satellite link. Breaking communication, or providing false information, may lead to total loss of control.

## Discussion

The shipping review provided by Allianz (AGCS, 2022, p. 14) for the last decade shows a continuous decline in maritime accidents that result in the loss of a vessel. It is proof of the effectiveness of measures implemented by the international community with the purpose of increasing the safety of maritime transport. The backbone of today's shipping consists of large vessels carrying large amounts of valuable cargo or substances toxic to the environment. Any accident with such vessels may create huge material losses and unrepairable environmental damage. The growing traffic density on the main shipping lanes increases the risk of an accident. Human factor was determined as the primary cause of maritime accidents (Cordon, Mestre & Walliser, 2015). The introduction of unmanned vessels, remotely controlled by highly qualified operators, or vessels with full autonomy will remove the weakest link from maritime operations. Systematically increasing crewing costs and shipowners' diminishing earnings (Clarksons, 2017) are gradually eroding the profitability of maritime shipping. The problem became more acute with the advent of the COVID-19 pandemic when crew costs skyrocketed.

Elimination of such costs not only improves the financial condition of the shipowners but also enables more investment in modern vessels. The shortage of competent crews has persisted for a long time. Improved work conditions on shore in developed countries have made seaman's jobs uncompetitive. Particularly the acute shortage of management-level officers with a technical background. Significant pay rises may mitigate this problem, but shipowners' tight budgets may not withstand it. Considering all the above, the introduction of autonomous vessels seems to be the correct response. Advances in technology allowed the building of a large-scale 80 meters long, fully functioning model of a fully autonomous vessel (YARA, 2022), which will provide valuable data for future projects. This development confirmed that necessary technologies are available today. Special attention needs to be given to rules that govern maritime shipping. Analysis of the regulatory barriers by the Danish Maritime Authority (Danish Maritime Authority, 2017) found several shortcomings of the existing regulations, which need to be rectified at either international or national levels by governments of coastal states before the use of autonomous vessels becomes feasible. IMO conducted a regulatory scoping exercise (IMO, 2022) and indicated the regulations to be amended; they also showed the necessity to create new ones. The conducted IMO exercise became a basis for work on future MASS codes. Satellite communication and navigation technologies, in use today, will require a hardening against unfriendly acts to prevent the hijacking or disabling of unmanned vessels, which could be targeted for their valuable cargo. Future projects need to account for very effective means that prevent unauthorized access.

## Conclusions

The introduction of autonomous vessels is a viable solution to problems that bother maritime transport. The human elements are the largest factor accountable for maritime accidents, the elimination of which may significantly improve the safety of naval transportation. Autonomous vessels should resolve problems with excessively high crewing costs and a short supply of competent crews, mainly officers. Such problems for shipowners are getting worse with time. The launch of the first large-scale, fully functional model of an autonomous vessel has proved the concept of unmanned vessels and the availability of the necessary technologies. Regulatory barriers at international and national levels require amendments to the existing rules and the creation of new ones. When introduced, an autonomous vessel will require an improvement of the existing communication and navigation technologies to make them more resilient to unfriendly acts.

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