Autonomous shipping and its impact on regulations, technologies, and industries

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ABSTRACT
The introduction of the maritime autonomous surface ships (MASS) accompanied by alternative fuels to the maritime industry is about to open a new era and lead to a new paradigm shift in terms of safety, security, and environmental protection. However, there are also some concerns on new technology which also can create new types of risks such as non-navigation risks and cybersecurity threats. This paper presents recent trends for developing autonomous vessels with the introduction of the latest projects around the globe. It also investigates the individual and combined impact of the MASS on regulations, technologies, and industries in response to the new paradigm shift in the maritime sector. Additionally, other key issues including safety, security, jobs and training, and legal and ethics are addressed to find a solution for an efficient, reliable, safe, and sustainable shipping in the near future. It is suggested that holistic approaches for developing the technology and regulatory framework are to be implemented, and the communication and cooperation of multiple stakeholders based on mutual understanding are vital for a successful arrival of the MASS in the maritime industry.

Introduction
A new paradigm shift is presently underway with rapidly evolving technology, taking into account marine alternative fuels that promise safer, greener, and more efficient ships in response to stringent requirements of international legislation more than ever. The initial shift started with the First Industrial Revolution in the 1800s when a mechanized power was introduced and vessels started to be propelled by steam using coal as a fuel. The next stage represented by the Second Industrial Revolution began when, in the early 1900s, the invention of diesel engines made the vessels more efficient and reliable using oil as a new fuel. The computerized control of ships was introduced in the 1970s in the Third Industrial Revolution represented by the internet-digital revolution. Now we are proceeding a step further towards the new paradigm associated with cyber-physical systems and autonomy as a part of “Shipping 4.0” (Rødseth 2017) with the introduction of gas as a fuel such as liquified natural gas (LNG).

In view of the question on why autonomous shipping is considered and investigated, Porahte, Prison, and Man (2014) present four reasons: the need for better crews’ working environment onboard and for mitigating the risk of future shortage of seafarers; the efforts to reduce transportation costs; the global need of reducing emissions; and the demand for improving the safety in shipping.

According to a 2010 report of the International Maritime Organization (IMO) submitted by the Baltic and International Maritime Council (BIMCO) and the International Shipping Federation (ISF), the shipping industry is anticipated to face a tightening labor market with recurrent shortages for ship officers (Lang 2010) due to hazardous working environment and prolonged periods away from land. The shipping industry has experienced downward pressure on freight rates and excess capacity under the fiercely competitive circumstance with economy of scale. With the introduction of low- or zero-carbon alternative fuels, the reduction of ship pollution and emissions and enhancement of ship safety are more demanding than ever (Kim et al. 2017).

Under these circumstances, the advent of autonomous vessels named Maritime Autonomous Surface Ship (MASS) will be a monumental incident that can either disrupt or induce the paradigm shift in the shipping industry and maritime transport system as a whole. The safe, effective, and efficient adoption and operation of MASS would depend on communication and collaboration among stakeholders, especially those engaged in the shipping and port industries.
Therefore, for a successful introduction and smooth settlement of MASS as well as relevant infrastructures in the maritime industry, key issues related to autonomous shipping and their impact on regulation, technology, and industry should be investigated with their relationship.

On the regulatory side, IMO (2017) decided to embark on the Regulatory Scoping Exercise (RSE) to determine the safe, secure, and environmentally sound operation of MASS. The RSE would be a complex issue since it will affect many areas including safety, security, interactions with ports, and pilotage in response to incidents and marine environment. As international maritime conventions such as the International Convention for the Safety of Life at Sea (SOLAS), International Regulations for Preventing Collisions at Sea (COLREG) and the Standards for Training and Certification of Watchkeepers (STCW) will be applied to MASS (IMO, 2018a), IMO Member States will be requested to review the scope of domestic laws, taking into account compliance with the RSE.

In terms of technology, using the latest Information and Communications Technology (ICT) systems, ships will be built with enhanced control capabilities, communication, and interfaces, and they will soon be operated by means of remote land-based or offshore services (Komianos 2018). The unmanned vessels are already in use for military, aerospace, or scientific purposes. Submersible-unmanned vehicles, such as the autonomous underwater vehicles (AUV) or the remotely operated vehicles (ROV), are also used and continue to be developed for deep-sea exploration. However, the technology replacing manning needs to outperform the crew in terms of safety, efficiency, and environmental protection (DNV GL 2018).

On the industrial side, it is easy to find a certain level of unmanned system in other modes of transport such as the airplane, train, and automobile industries where autonomous vehicles are already under development. Regarding the maritime industry, MASS is expected to change shipbuilding, equipment and device, and shipping and port infrastructures substantially. Maritime industries related to autonomy, automation, unmanned operation, big data, enterprise-grade connectivity, and analytics will be steadily expanded (Komianos 2018). Therefore, in order to successfully introduce MASS, proper communication and cooperation with relevant stakeholders, especially the shipping, shipbuilding, and port industries must be preceded.

In this research, the latest projects were firstly introduced on global trends for developing autonomous vessels. Secondly, the impact of MASS on regulations, technologies, and industries has been investigated with their relationship to identify both past and future works to prepare for the new paradigm shift in the maritime sector. Finally, other key issues related to safety, security, jobs, training, ethics, liability, and insurance were discussed in an effort to find an insight for efficient, reliable, safe, and sustainable shipping in the future. It should be noted that this research focuses on the identification of issues on autonomous shipping and its impact on regulations, technologies, and maritime industries, and autonomous ships not having seafarers on board (i.e. over degrees of MASS 3.0).

**Global trends of autonomous vessels**

In the past decade, with a variety of multi-national projects with massive investment and research and development for autonomous vehicles, i.e. self-driving cars, projects for the development of autonomous ships have been launched all over the world. Many organizations such as Rolls Royce, DNV GL, Norwegian University of Science and Technology (NTNU), and Norway-based Kongsberg have all revealed ambitious plans to develop all-electric and autonomous container ships by 2020 as listed with main characteristics of their projects in Table 1. Their race is getting fiercer as closing to the finish line. Other organizations throughout the world are developing complementary, even competing concepts and systems to support unmanned operations, coupled with infrastructure initiatives, including autonomous ports and high bandwidth communications.

| Project name (Period) | Participating institutions | Main characteristics |
|-----------------------|---------------------------|----------------------|
| **MUNIN (2012 ~ 2015)** | 8 research and industry partners in Europe | • Development of a concept for an autonomous dry bulk carrier (length: 200 m) • Development of sensor, navigation, and communication systems • 100TEU containership (length: 60 m) • Autonomous • Fully battery powered (300 kWh) • Standard development of safety, policy, economy, and society • Requirement development for Safety and reliable performance • 120TEU containership (length: 80 m) • Remote test (2019), fully autonomous (2020) • 3 remote operation center onshore • Route: Heroya/Brevik/Larvic (12 nautical miles) |
| **ReVolt (2014 ~ 2018)** | DNV GL, NTNU | |
| **AAWA (2015 ~ 2018)** | Rolls Royce, DNV GL, etc. | |
| **YARA Birkeland (2017 ~ 2020)** | Kongsberg, YARA, NTNU, DNV GL | |
In 2012, the Maritime Unmanned Navigation through Intelligence in Networks (MUNIN) funded by the European Commission started to investigate the feasibility of unmanned ships in multi-disciplinary points: technical maturity; economic benefits; social impact; and safety (at least as safe as manned vessels) during deep-sea voyages (Burmeister et al. 2014; Porathe, Prison, and Man 2014; MUNIN 2015).

Following the MUNIN project, the ReVolt was commenced as a dedicated research project to develop an unmanned, zero-emission, and short sea vessel by DNV GL in collaboration with NTNU in order to manage the traffic congestion in urban areas on the EU’s road network (DNV GL 2018; Komianos 2018).

Another representative project associated with autonomous vessels is the Advanced Autonomous Waterborne Applications Initiative (AAWA) which was launched by Rolls-Royce in 2015. This project invited various partners – universities, ship designers, equipment manufacturers, and classification societies in order to examine the economic, social, legal, regulatory, and technological barriers to be addressed to make autonomous ships a reality. It is aimed to develop preliminary designs with the technical specification for the next generation of advanced ship solutions (Komianos 2018).

One of the latest projects related to the autonomous ship is the YARA Birkeland (Kongsberg Maritime AS 2018). YARA and Kongsberg have partnered to construct the world’s first fully electric container feeder vessel. The project started in 2017 working towards remote operation by 2019 and is scheduled to go fully autonomous by 2020. Instead of ballast tanks, the ship is designed to use battery packs as permanent ballast. Additionally, she would be able to be berthed automatically or go underway without any human intervention by using an automatic mooring system. By removing up to 40,000 truck journeys in populated urban areas, it is expected to reduce NOx and CO2 emissions significantly, whereas improving road safety and alleviating traffic congestion, which will thus contribute to achieving UN sustainable development goals (UN, 2015).

Impact on regulation

A recent foundering of the Costa Concordia in 2012, which ironically marks the first century after the Titanic sinking in the North Atlantic Ocean in 1912, has shown that even after 100 years, accidents can occur on ships that are considered masterpieces of modern technology along with remarkable regulatory and technological advancements in the maritime safety (Schröder-Hinrichs, Hollnagel, and Baldauf 2012).

Therefore, despite the rapid development of science and technology in the maritime industry, autonomous vessels indisputably need to be subject to the international regulations necessary for the vessels to operate safely across nations and even the sea bed areas beyond national jurisdiction. Although some regulatory aspects of manned vessels may be compatible with unmanned vessels, such as certain clauses of the International Safety Management (ISM) Code, there is a need for specific international regulations taking into account the characteristics of unmanned vessels as well.

Recently, a draft request for RSE was submitted to Maritime Safety Committee (MSC) and the RSE was accepted into the MSC work program at MSC 98 (IMO 2017) to ensure the safety, security, and environmentally soundness of MASS. At MSC 99, a work plan for the RSE was agreed (IMO 2018a) to finalize this exercise by 2020. The updated work plan is presented in Table 2.

The objective of the RSE for MASS is to assess the degree of autonomy that may affect existing regulatory frameworks in order to address MASS operations. To facilitate the process of the RSE, the degrees of autonomy were categorized into four phases at MSC 100 (IMO 2018b) as shown in Figure 1. It should be noted that MASS could operate in more than one degree of autonomy during a single voyage.

The amendment of all conventions will require time-consuming tasks, which may not be a practical approach. All IMO committees and subcommittees will have to work together for this enormous revision. For this reason, the goal-based approach should be applied to develop new regulatory requirements. Recently, the MSC approved the revision of Generic guidelines for developing IMO goal-based standards (GBS) to set safety goals and functional requirements, taking into account the entire lifecycle of MASS (IMO 2019a). In addition to the GBS, risk assessment and software quality assurance (SQA) will be required for the safety of MASS in both the real and cyber world.

### Table 2. Work for the regulatory scoping exercise (IMO 2018a, 2019b).

| Task                                           | MSC 100 (Dec. 2018) | MSC 101 (June 2019) | ICG/WG (Sep. 2019) | MSC 102 (May 2020) | MSC 103 (Nov./Dec. 2020) |
|------------------------------------------------|----------------------|----------------------|--------------------|----------------------|--------------------------|
| Framework (definitions, list of instruments, etc.) | ×                    | ×                    | ×                  | × (if required)      | ×                       |
| First step (identification of provisions in IMO instruments) | ×                    | ×                    | ×                  | × (if required)      | ×                       |
| Second step (analysis to determine the most appropriate way of addressing MASS operations) | ×                    | ×                    | ×                  | ×                    | ×                       |
| Interim guidelines for MASS trials              | ×                    | ×                    | ×                  | ×                    | ×                       |
Even in this case, the requirements should be formulated in at least two versions: fully autonomous or fully remote control; available in various combinations of autonomous and remote control. Since the shipping market continues to be flooded with new and better technologies, it is unrealistic to formulate detailed technical requirements for algorithms, sensors, data fusion, etc., at the IMO level. It is, therefore, suggested that the code should be goal-based. The aim of the GBS is that autonomous and remote-controlled ships should be as safe as conventional ships of the same or similar types. (DNV GL 2018).

**Impact on technology**

Based on rapidly growing scientific and technological potential for several decades, substantial changes have been taking place in the globe, affecting all areas of humanity as well as the terrestrial and aquatic environment.

Autonomous vessels feature a technology similar to self-driving cars and use a range of physical sensors to control autonomous functions, including Global Positioning System (GPS); Inertial Navigation System (INS); optical and Infra-Red (IR) cameras; Light Detection And Ranging (LIDAR); RAdio Detecting And Ranging (RADAR); high-resolution sonar; microphones; and wind and pressure sensors. Expected entities required for MASS are presented for each system, respectively, in Table 3.

More recently, maritime has begun to make use of other technologies for general communications. Commercial cellular 3 G/4 G networks can provide ship-to-shore coverage up to 30 km off the coast (Lloyds Register (LR) 2017). In the past, the provision of the Internet to crew and passengers was too difficult or expensive (Porathe, Prison, and Man 2014). Since isolated lifestyles hinder potential young seafarers from entering the shipping industry, the internet access can be a key differentiator for crew members to maintain their careers on ships.

One of the biggest challenges in developing the technology for MASS is to demonstrate that unmanned systems are at least as safe as a manned ship system and to provide the SCC with adequate situation awareness. In case of emergency situations such as stranding or evasive maneuvering, the ship systems should be remotely monitored and controlled by the operators of the SCC receiving crucial information via satellite at short time intervals. The SCC should also have a smart alarm system and the ability to switch to the manual control mode in case of doubt on the autonomous system. Figure 2 shows MASS and SCC systems with essential equipment and functions and their relationship formed by data and information via satellite.

Particularly, with respect to sensors that support monitoring and decision from SCC, the reliability of the sensors must be ensured through design approval as well as remote and on-premise testing and periodic inspections. Sensor failures cause a serious threat to the safety of the system. The most important safety sensors should consider homogeneous and/or heterogeneous redundancy, and diagnostics, and/or prognosis. It should be noted that heterogeneous redundancy is more reliable than others since it can reduce the dependency on sensor types (DNV GL 2018). Additionally, due to lack of failure data and no

![Figure 1. Degrees of autonomy.](image)

![Table 3. Systems and entities expected to be required for MASS.](table)

| Systems                        | Description                                                                 | Expected entities                                                                 |
|-------------------------------|-----------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| Autonomous navigation system  | Route voyage planning in accordance with legislation and autonomous seamanship | ● GPS, INS ● Autonomous seamanship taking into account arising navigational accidents (e.g. collision, grounding) or weather changes |
| Advanced sensor module        | Watchkeeping on board vessels by continuously fusing sensor data            | ● RADAR, AIS, LIDAR, IR camera, high-resolution sonar, wind, and pressure sensors |
| Machinery, monitoring and control system | Machinery automation system with certain failure prediction functionalities | ● Keeping optimal efficiency ● Additional pump-jet acting as rudder and propulsion redundancy ● Skilled nautical officers and engineers |
| Shore Control Centre (SCC)    | Continuously monitoring and controlling MASS                                 |                                                                                   |
easy access to the data, a more detailed elicitation of experts could be beneficial to resolve some issues pertaining to hazards threatening the safe and efficient operations of autonomous ships.

All equipment and device installed onboard should also be interconnected and integrated to enable collection, management, and analysis of data. They are required to be equipped with a high level of redundancy and durability, and to be highly modular to avoid failures.

Lower communication is required by a higher level of autonomy where the on-board processing system analyses the data for detection, tracking, classification, and recognition of objects of interest. But it should be noted that the higher level of autonomy a ship has, the more crucial and significant accident the ship could cause.

Impact on industry

For hundreds of years, the shipping industry has relied on knowledges and experience of ship crews. Today, autonomous technology is poised to reshape the maritime sector with unmanned vessels. Small unmanned crafts have already begun service, while the technology for larger vessels is under development. It is time for the maritime industry to embrace autonomy and to understand how autonomy will shape the future industry and how best to utilize it. MASS will have an impact on ship design, shipbuilding, port infrastructure including services and interfaces. Automation will transform on-shore elements of shipping from port infrastructure and cargo handling through to the land-based logistics and transportation chain. One of the goals of the logistic industry is a timely service that allows shippers and customers to instantaneously tailor dispatches and receive deliveries from this autonomous logistics transport chain (Lloyds Register (LR) 2017). For a successful introduction of the MASS to the maritime industry, communication and cooperation of its stakeholders based on mutual understanding will be vital. Main stakeholders and their relationship are depicted in Figure 3. Seafarers onboard/onshore; insurance company; cargo and bunkering companies; research institution; university; and training center in the maritime sector would be stakeholders.

Additionally, autonomous vessels will contribute to transforming the existing industries into new innovative types of industries that can improve the existing vessels; system integration and control; system management and maintenance; SCC operation and management; fleet management; cybersecurity; big data analysis; smart sensor; and communication. Moreover, for the successful introduction of the MASS, development, amendment, and interpretation of maritime rules and regulations together with communication and cooperation of the stakeholders are also required to make the autonomous ships efficient and reliable.

Other issues on MASS

Safety issues

It is perceivable that the automation can lead us to a safer environment since it is able to address human shortcomings like fatigue, attention span, information overload, and normality bias on the possibility of accidents (Porathe et al. 2018). In the United States Coast Guard (USCG) report, the marine causalities caused by
human error were between 75-96% (Rothblum et al. 2002). These errors were the result of fatigue, shortfalls in maintenance and standards, inadequate knowledge and information, and poor communication skills. On the other hand, in a study of the MUNIN project on the quantitative safety assessment of an unmanned bulk carrier, the unmanned ship can be expected to be safer than conventional ships despite acknowledging that they lack vital information pertaining to her design and operation (Rødseth and Burmeister 2015).

New technology also opens for new types of accidents. Results of a study (Wróbel, Montewka, and Kujala 2017) showed that while navigation risks such as collision and stranding may decrease, non-navigation risks including fire, explosion, and flooding may rather increase on autonomous ships. Potential risks with the introduction of the MASS are presented with some examples in Table 4.

Therefore, risk assessment can be served to demonstrate a certain level of risk and an important tool for making relevant design decisions. Due to the complexity of autonomous marine system, there lacks relevant knowledge, information, and experiences. Given this, it may be challenging to determine the complete risk level for the MASS considering a wide range of uncertainties in accidental scenarios, probabilities, and severities (Porathe et al. 2018).

### Security issues

Due to the high reliance on software and connectivity, cybersecurity risk has emerged as a matter of remote control and management of autonomous ships. Since the autonomous ship concept will depend heavily on information technology systems onboard and onshore, cyber-attacks are far more likely than conventional vessels. For the remote control function, cyber terrorists could hack the communication link to control the function directly. The more dependent a ship’s operation is on software and communications, the more vulnerable it is to these threats (DNV GL 2018). Furthermore, as malicious activity grows and new technologies emerge, such as the Internet of Things (IoT), new security challenges will materialize, and the suitable protection of systems, networks, and data in cyberspace will be more needed than ever.

In 2016, IMO identified a number of key areas in the maritime sector associated with potential cyber-

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Table 4. Potential risks following the introduction of MASS (Komianos 2018).

| Risk                             | Example                                                                 |
|---------------------------------|------------------------------------------------------------------------|
| Rise of cyber security threats  | • Hacker attacks to adduct ship and hijack cargo                        |
|                                 | • Leakage of sensitive information on cargo and costumer               |
| Failure of equipment or device  | • Failure of ship due to failure of key operation systems including propulsion system |
|                                 | • Failure of information and communication system required for autonomous operation |
| Error or distortion of information | • Distortion of information communicated with SCC including information on ship operation |
| Difficulty of recognizing accident | • Failure or delay of onshore operator to recognize the occurrence of accident |
| Challenge of cargo management  | • Safety-related problems such as cargo being set on fire without seafarer onboard |
| Threat against port security   | • Weaponization of autonomous ships                                    |
related risks that include but are not limited to bridge systems; cargo handling and management systems; propulsion and machinery management and power control systems; access and control systems; communication systems; and personnel (IMO 2016).

MASS may change the patterns of pirate, terrorist, and criminal activities. Cases of human loss including hostage situations and kidnapping by pirates and armed robberies may be decreased. However, the absence of ship crews can lead to an increase in attempts to hijack the vessel itself for valuable cargo. There is also the inherent risk that MASS can be abused for crimes such as illegal cargo transport, including arms and drugs. Technical and institutional considerations should take place to strengthen port security by developing new inspection mechanisms or changing the place of inspection, if needed.

**Issues on jobs and training**

While growing fast, the maritime industry is struggling to find adequately skilled seafarers. In particular, Lloyds Register (LR) (2017) predicted significant shortfalls of qualified officers and crews from 2025. Moreover, the advent of MASS has raised concerns on the decline in the number of seafarers and jobs which are expected to be replaced by Artificial Intelligence (AI) and autonomous systems.

On the other hand, the opportunity for new business and job creation will be followed by this trend, which will require highly skilled crews and operators especially with expertise in technology and IT systems. The predicted deficit of labor could be offset by deploying automation. Remote and autonomous operations will transfer many seafaring jobs to land-based SCC, opening up the industry to a new set of people who will find a maritime career, onshore, a more attractive proposition. It is also anticipated that autonomous ships will enhance the quality of life of seafarers. If ships are controlled from the shore, the difficulty stemming from staying on board for a long period of time and the risks of marine accidents will be alleviated.

In the face of the decreasing number of seafarers, it will be very important to develop qualification standards for on-shore operators of MASS and to provide relevant training and education. The operators should be certified as appropriate under the International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers (STCW) Convention. It might be also necessary to consider developing new qualification standards in the STCW Convention or new Knowledge, Understanding, and Proficiencies (KUP).

**Legal and ethical issues**

Businesses have adopted advanced and new technologies in order to improve business performance, reduce costs, and enhance safety. However, the gap between the time taken to develop and exploit technology and the ability of regulators to develop codes and practices gives rise to vulnerabilities, while the timing and the type of regulatory intervention can accelerate, retard, or prevent the adoption of the technologies taking into account mutual influence between regulations and technologies. Therefore, to take full advantage of the benefits of the technologies, efficient approaches to regulation are required in a timely manner.

Traditionally, we have always ascribed responsibility to human agents or organizations considered legal entities, such as a shipping company. It is difficult to ascribe responsibility for wrongdoing to an algorithm when it is not considered a moral or a legal agent. This challenge is widely discussed in relation to the automotive industry. The debate on the safety of self-driving cars includes the testing of traditional examples of moral dilemmas (Etzioni and Etzioni 2017). As an example for the MASS, the ISM Code (SOLAS Chapter IX) requirements to identify a legal entity responsible for the safe operation of ships and pollution prevention will remain (DNV GL 2018).

In the process of developing and adopting autonomous ships, a wide variety of ethical issues are expected to be raised. In the past, communication for ship operation has been dominated by human, while, in the case of MASS, it is expected to be diversified to man-machine and machine-machine communication. It is necessary to review scenarios in which communication with machines fails or is rejected. The development of a technology equipped with the ability to respond to every possible scenario is so challenging that the boundary setting for legal liability will be another issue, especially establishing reasonable criteria and scope on responsibility between shipowner and manufacturer including an appropriate security structure for insurance coverage.

For the sake of an example, here is a question regarding the ethical issue. A MASS was assumed to navigate along the most economic route. Nearby the MASS, a manned passenger ship was capsized, communication systems were unavailable or misleading between the MASS and the manned ship, while her crew and passengers on the capsized ship were nothing but to wait for a help. Unfortunately, the MASS may not able to recognize the accidental situation of the passenger ship at risk. Who is responsible for neither recognizing the ship nor fulfilling duties of rescue?

**Conclusions**

The introduction of the MASS with alternative fuels to the maritime industry will open up a new era and bring about a new paradigm shift in terms of cost efficiency, accident prevention, and human resources. However,
new and very distinct issues related to safety, security, and environmental protection conventions and regulations must be resolved. Therefore, more holistic, international, and consolidated approaches for new regulatory frameworks to the MASS are to be taken into account before the introduction of MASS into commercial shipping in order to ensure the prevention of maritime accidents and the protection of the environment. It is also important to understand the impact of the MASS on regulations, technologies, and industries, and relationships between relevant stakeholders.

In this paper, recent trends for developing autonomous vessels are firstly presented along with the latest global projects. While a number of projects have been already carried out as preliminary studies, various projects are ongoing or upcoming throughout the world to develop pilot ships, even competing concepts and systems to support unmanned operations, coupled with infrastructure initiatives, including autonomous ports and high bandwidth communications.

Secondly, the impact of the MASS on regulations, technologies, and industries has been identified with multilateral influences. Regarding the international regulations, RSE was accepted into an MSC work program to determine how the safe, secure, and environmentally sound operation of the MASS might be addressed in IMO instruments. The amendment of all relevant conventions will require lots of tasks with significant time. Therefore, GBS, risk assessment, and SQA are prerequisites for the safety of the MASS in both the real and cyber world. The great challenge to develop technologies for the MASS will be to demonstrate that unmanned systems are at least as safe as manned ship system and to provide SCC with situation awareness, especially in cases of emergency situations. The MASS should be remotely monitored and controlled by the operators of the SCC with a smart alarm system receiving necessary and crucial information via satellite. Systems and sensors required for the MASS and SCC shall be defined and developed, and their synergetic impacts should be closely reviewed. Especially, equipment and device installed onboard will have to be integrated to collect, manage, and analyze data from the MASS efficiently. They will have a high degree of redundancy and durability as well as will be highly modularized to avoid failures. The MASS will have an impact on ship design, shipbuilding, port infrastructure including services and interfaces. Communication and cooperation of multiple stakeholders based on mutual understanding will be vital for a successful introduction of the MASS to the maritime industries including shipping, shipbuilding, equipment manufacturing, classification society, etc.

Thirdly, other issues including safety, security, jobs and training, and legal and ethics were examined. Unmanned vessels are expected to be safer than conventional vessels. But new technology also opens for new types of risks such as non-navigation risks including fire, explosion and flooding, cybersecurity threats, and error of information. MASS may contribute to changing the patterns of pirate, terrorist, and criminal activities. Technical and institutional considerations should take place to strengthen the security by developing new inspection mechanisms. While anticipating the decrease in the number of seafarers, it will be highly important to develop the qualification standards for on-shore operators of MASS and to provide relevant training and education. Regarding the legal and ethical issues, the disparity between the time for technological maturity and the time to develop relevant regulations and practices may cause a negative impact on the timely adoption of the technologies. Therefore, readdressing approaches to regulation is needed in order to fully exploit the benefits of the technologies in a timely manner. Autonomous ships are also expected to raise a wide variety of ethical issues, especially emergency cases such as miscommunication between human and machines as well as machine and machine, and search and rescue of ships and crews/passengers who need an urgent help.

Finally, a number of significant challenges still remain to be resolved, but the benefits to the environment, business, and society will necessitate multidisciplinary actions to address these issues on the MASS. The most important task of a sustainable development in the maritime industry of the future is to understand all these dimensions and their interconnections to achieve minimal safety risk, minimal environmental impact, and maximum commercial benefits. As a future work following this study, a quantitative analysis for the impact of the MASS on regulations, technologies, and industries including economic effects on the industrial side will be addressed in detail.

Acknowledgments

This work was supported by the Ministry of Oceans and Fisheries, the Republic of Korea, through 2019 IMO strategic program (No. 20190131307-00). Their supports are greatly appreciated.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the Ministry of Oceans and Fisheries, Republic of Korea, through 2019 IMO Strategic Programme (No. 20190131307-00).

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