Technology assessment on the autonomous ships: key findings and recommendations

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Abstract. Maritime autonomous surface ship (MASS) has been developed rapidly. MASS could be disruptive technology that will bring about a paradigm shift in related industries as well as the maritime transport system. Due to huge implications and uncertainties, it is required to understand complex socio-economic behaviour induced by MASS for the international society. This paper presents the key findings and some recommendations from technology assessment on MASS which investigated the potential effects from MASS in terms of economic, social, cultural and ethical aspects. The results can be used to design a future driven by MASS in a desirable direction.

1. Background
Recently, advances in technology spanning digitalization, big data and Artificial Intelligence (AI) have reached a level where commercialization of not only autonomous vehicles, but also autonomous ships are imminent. The development of technology controlling ships from shore has been progressing at a rapid pace, especially driven by the industry [1-5]. In 2017, the International Maritime Organization (IMO) decided to adopt as one of its seven Strategic Directions to be pursued for the 2018-2023 timeframe, “Integrate new and advancing technologies in the regulatory framework” [6]. In June 2018, the Maritime Safety Committee (MSC) of IMO decided to embark on the Regulatory Scoping Exercise (RSE) to adopt and operate Maritime Autonomous Surface Ships (MASS) [7].

As a result, the global community has been called to make various efforts in technical, political and social aspects to accommodate MASS. MASS is not merely one of many sides of technological progress. It will be an innovation that disrupts, reconstructs and induces a paradigm shift in the shipping industry and maritime transport system as a whole. In order to guide the future in a desirable direction under such change, the international society should be able to understand the economic and social dynamics encompassing maritime safety, environmental protection, seafarer welfare, training and education, liability, insurance and ethical concerns. In addition, communication and cooperation of multiple stakeholders will be a prerequisite to ensure a safe, effective and efficient maritime transport system with MASS. In this regard, We have carried out technology assessment to not only provide useful guideline for policymakers but also contribute to forming social discourse surrounding MASS.

The remainder of the paper is as follows: Section 2 presents the brief procedure and methodologies of technology assessment; Section 3 describes key findings and discussions from the technology assessment; some recommendations are suggested in Section 4; and finally results are summarized in Section 5.
2. Technology Assessment: Procedure and Methodology

We conducted a technology assessment on MASS as per Article 15 of the Marine Science and Technology Cultivation Act that took effect in June 2017. Main purpose of this assessment is to explore the economic, social, cultural, ethical and environmental impact of the new technology, thereby maximizing benefits and preparing against negative side effects. The outcome would serve as a guideline for reasonable policy-making. Also, the assessment is expected to facilitate communication among diverse members of the society and contribute to forming social discourse to ease the ripple effect of new technology and promote social acceptance.

The assessment was led by a working group that consists of 27 experts from a number of areas including technology, economics and society. Additional contributions were also made by 11 groups of key stakeholders from wide-ranging fields such as labour unions of seafarers, marine pilot groups, key industries including shipping, shipbuilding and equipment and device businesses, the public sector including Vessel Traffic Centers, and students who will drive the development of maritime transport in the future. The assessment addresses various effects that may arise upon the introduction and operation of MASS including industry stakeholders, changes in risk factor, legal issues, education and training, ethical concerns, liability and insurance.

The working group which was divided into three sub-groups, i.e. technology-, economy- and society-subgroup, assessed cross-disciplinary issues surrounding MASS via a total of twelve meetings for focus group interview (FGI), stakeholder surveys and media analysis. The details of those procedure and methodologies can be found in [8].

A definition on "Autonomous Ship" that is universally agreed upon in the international society is yet to exist. "Autonomous" and "Unmanned" are clearly different ideas. However, the "Autonomous Ship" studied in the technology assessment is defined as "all ships equipped with full-scale or partial autonomous systems operated without human intervention". Thus, it includes "Unmanned Ship" such as ships remotely operated from shore without any seafarer on board.

The technology assessment has been focused on surface cargo ships such as containerships and bulk carriers. However, ships that transport hazardous materials including oil tankers were precluded from the study in that their acceptance levels are predicted to be relatively low. Passenger ships, cruises, fishing vessels and warships were also excluded.

It is worthwhile to mention that the technology assessment, as a multidisciplinary review, has been implemented to forecast diverse impacts in a wide-ranging area including the economy, society, culture, ethics and environment. Basic assumptions must be set for experts from numerous fields and members of the society to explore a single theme together. The following are the key technology of the future and subsequent changes that were presumed for the assessment [8,9]:

- Ships will be operated by remote control from shore or even without remote control from shore (fully autonomous), in which case minimum human intervention is made only in emergency.

- Key information on ships will be monitored from the shore. Frequency of maintenance and repair will be optimized through the use of big data. Even during operation on waters, minimum maintenance and repair can be conducted with the help of technology such as drones.

- Bridge and accommodation will be removed to expand cargo space and improve arrangement of on-board equipment and devices.

- Exterior design of ships will change. Closed structure design could be adopted to prevent hijacking of cargo by pirates. But external access for maintenance and repair, and ease of loading / unloading will also be considered.

- Every equipment and device installed on board will be interconnected and integrated to enable collection, management and analysis of data. They will be equipped with a high level of redundancy and durability, and will be highly modular to avoid failure.
• Not only navigation, but also docking and maneuvering will be remotely controlled or fully automated. In support, port infrastructure will be transformed.

3. Key Findings

3.1. Ecosystems and Stakeholders
In the long run, MASS will bring about sea change to shipbuilding, equipment and device, and shipping and port industries. Especially, shipping and port industries (see Figure 1) form a dynamic ecosystem, in which numerous stakeholders participate compared to shipbuilding, equipment and device industries (see Figure 2). For large parts of this ecosystem, public and private sectors are intertwined through complex regulations. On top of this, a variety of new stakeholders related to MASS are expected to emerge in the ecosystem such as telecommunication service providers and maritime cyber security businesses. The safe, effective and efficient adoption and operation of MASS hinges on communication and collaboration among such stakeholders, especially the shipping and port industries. Detailed procedure and information for preparing Figs. 1 and Fig. 2 can also be found in [8].

![Figure 1. Stakeholders of Shipping and Port Industries of the ROK.](image-url)
3.2. Changes in Risk Factor
The main cause of maritime accidents is human error, which in fact takes account for around 79% of maritime accidents in the ROK (see Table. 1). However, the introduction of MASS is predicted to change the causes of maritime accidents. MASS reaching autonomy levels 3 (remotely controlled ship without seafarers on board) and 4 (fully autonomous), based on IMO’s preliminary degrees of autonomy [10], are widely anticipated to reduce human error since they are operated without seafarers [11].

Yet, the absence of seafarers exacerbates the concern that there will be no skilled manpower capable of responding in the event of an accident. According to a study, while risks of navigational accidents such as collision and stranding may decrease, risks of non-navigational accidents including fire, explosion and flooding may rather increase on autonomous ships [12]. To ensure a safe maritime transport system, technical and institutional measures to respond to diverse types of accidents should be derived rather than vaguely anticipating that the occurrence of human errors will decline with the emergence of MASS.

In the future, causes of accidents that have been minimal in number or that have not been recognized as important risk factors could stand out as well. In particular, cyber security is recognized as one of the prerequisites to enable practical operation of MASS. It should be understood that autonomous ships equipped with the same or similar system could be exposed to cyber threats simultaneously. Defects in equipment and devices including autonomous operating systems, information error and distortion, difficulty of recognizing accidents and challenges in cargo management could be all potential threats against maritime safety (see Table. 2).

MASS may drive changes in the patterns of pirate, terrorist and criminal activities. Cases of human loss including hostage situations and kidnapping by pirates and armed robberies may decrease. But attempts at abducting the ship itself targeting valuable cargo may increase due to the absence of seafarers. There is also the inherent risk that MASS may be abused for crime such as transport of illegal cargo including arms and drugs. Thus, the existing Customs, Immigration and Quarantine (CIQ) procedure centered on human may turn out to be ineffective for MASS. Technical and institutional considerations should take place to strengthen port security by developing new inspection mechanisms or changing the place of inspection if needed. In this regard, the CIQ using electronic means need to be taken into consideration with MASS.
Table 1. Cause of Maritime Accidents of the ROK for the past 5 years (2013-2017)

| Cause                                                                 | Cases | Ratio |
|------------------------------------------------------------------------|-------|-------|
| Insufficient preparation of departure                                  | 17    | 1.1%  |
| Insufficient survey of nautical conditions                             | 0     | 0.0%  |
| Poor management of voyage plan                                        | 4     | 0.3%  |
| Negligence of evaluating ship location                                | 39    | 2.6%  |
| Inappropriate maneuvering                                              | 55    | 3.6%  |
| Negligence of look-out                                                | 744   | 48.9% |
| Insufficient preparation and response to heavy weather                 | 27    | 1.8%  |
| Inappropriate anchoring and mooring                                   | 9     | 0.6%  |
| Violation of navigation rules                                         | 128   | 8.4%  |
| Negligence of duty and supervision                                     | 12    | 0.8%  |
| Negligence of watch keeping                                          | 29    | 1.9%  |
| Other navigation errors                                               | 18    | 1.2%  |
| Incompliance with safe working regulations on board                    | 120   | 7.9%  |
| Total                                                                  | 1,202 | 79.0% |

| Cause                                                                 | Cases | Ratio |
|------------------------------------------------------------------------|-------|-------|
| Deficiency of hull and machinery                                      | 81    | 5.3%  |
| Poor maintenance of machinery                                         | 98    | 6.4%  |
| Poor management of inflammable equipment and deficiency of wires      | 12    | 0.8%  |
| Inappropriate stowage of passenger and cargo                          | 14    | 0.9%  |
| Inappropriate management for ship operation                            | 50    | 3.3%  |
| Inappropriate crew management                                         | 1     | 0.1%  |
| Inappropriate provision of AtoN service                               | 8     | 0.5%  |
| Weather and force majeure                                             | 36    | 2.4%  |
| Others                                                                 | 20    | 1.3%  |
| Total                                                                  | 129   | 8.5%  |

| Cause                                                                 | Cases | Ratio |
|------------------------------------------------------------------------|-------|-------|
| Total                                                                  | 1,522 | 100.0%|

Source: Korea Statistical Information System
Table. 2. Examples of Potential New Risk Factors against Maritime Safety

| No. | Risk Factor                      | Example                                                                 |
|-----|----------------------------------|-------------------------------------------------------------------------|
| 1   | Rise of cyber security threats   | • Hacker attacks to abduct ship or hijack cargo                          |
|     |                                  | • Leakage of sensitive information on cargo and customer                |
| 2   | 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 such as failure of communication |
| 3   | Error or distortion of information | • Distortion of information communicated with on-shore control center including information on ship operation |
| 4   | Difficulty of recognizing accident | • Failure or delay of on-shore ship operator to recognize the occurrence of accident |
| 5   | Challenge of cargo management    | • Safety-related problems such as cargo being set on fire without seafarer on board |
| 6   | Threat against port security     | • Weaponization of autonomous ships                                    |

3.3. Legal Issues
The legal status of MASS is yet to be determined, but their concept is expected to change. As human seaworthiness is reduced going forward, ships will no longer remain passive subjects operated by seafarers. Instead, they may gradually transform into active agents that make small and big decisions to achieve safety and efficiency of operation.

A legal controversy surrounding MASS may emerge in regards to the United Nations Convention on the Law of the Sea (UNCLOS), most likely in that it would be difficult to secure effectiveness of enforcement when coastal states exercise jurisdiction (see Figure. 3).

As most international maritime conventions such as the International Convention for the Safety of Life at Sea (SOLAS) and International Regulations for Preventing Collisions at Sea (COLREG) will be applied to MASS as well, global society will also need to review the scope of domestic laws alongside the RSE.

3.4. Jobs, Education and Training
The emergence of MASS has been driving concerns on the decline in the number of seafarers and jobs. 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. At the same time, high-caliber workforce equipped with the skill for operating MASS from shore may be able to enjoy higher income and improved welfare.

It is clear that the advent of MASS will significantly change the landscape of jobs related to seafarers. The minimum safe manning level is sure to be decreased and the jobs will be replaced by AI and autonomous systems, just to start with. Therefore, operators capable of maneuvering the ships from shore and backed by relevant certification will be in high demand.

In the face of the decreasing number of seafarers, it would be significant to develop qualification standards for on-shore operators of MASS and to provide relevant training and education. Operators must have basic knowledge on issues such as navigation safety, terrestrial and coastal navigation, planning and conducting passage and determining position, navigation equipment, meteorology and
emergency procedures. In the case of an emergency on board, operators must be able to clearly recognize the situation and mobilize basic skills and knowledge as deck officers to respond to danger. Hence, they should be certified as appropriate under the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) Convention. If needed, it might be necessary to add new qualification standards in the STCW Convention or new Knowledge, Understanding and Proficiencies (KUP). These efforts will help appeal the attractiveness of working as seafarers or on-shore operators to the youth. Given the short on-board experience of young seafarers as evidenced in the past, hiring them as on-shore operators of MASS may contribute to guaranteeing continuity of their career as seafarers.

3.5. Ethical Concerns
In the process of developing and adopting autonomous ships, a wide variety of ethical issues are expected to be raised. The controversy surrounding autonomous vehicles in the auto industry, which is a step ahead in applying automation, gives a glimpse of what the future holds for autonomous ships. Yet, ethical concerns can be compounded with autonomous ships given the special circumstances of navigating on sea. Thus, such issues should be dealt with in a serious manner.

3.6. Liability and Insurance
Just like other unmanned vehicles, MASS is expected to bring about a shift in the liability structure regarding maritime accidents. It is likely that the liability of manufacturers in the case of MASS will increase in relativity to conventional manned ships. However, pinpointing who to blame can be even more of a challenge due to reasons including modification of ships and failure to update autonomous operation systems in a timely manner. Especially, setting reasonable criteria and scope on liability between shipowner and manufacturer, and an appropriate security structure for insurance coverage such as who should make compensations...
first and exercise the right to indemnity afterwards will be tricky issues. In this regard, views of multiple stakeholders should be reflected to consider the public benefit of accommodating MASS while allowing swift remedy for victims in a comprehensive manner. Other issues to be deliberated include whether it is appropriate to maintain the shipowners' limitation of liability system in the case of MASS in light of higher ship price, different liability structure and subsequent burden. It would be worthwhile considering to adopt the mandatory insurance system following certain international maritime conventions including the International Convention on Civil Liability for Bunker Oil Pollution Damage, the Nairobi International Convention on the Removal of Wrecks and the case of autonomous vehicles in several countries.

4. Recommendations for Future Discussion

4.1. Technology and Industry
Once the IMO’s Regulatory Scoping Exercise (RSE) is completed, not only establishment and amendment of IMO Conventions related to MASS, but also standardization of core technology should be carried out. There are several key organizations who will possibly address those regulation and standardization issues of MASS. Building a cooperative framework would help raise efficiency as various international organizations such as IMO, International Organization for Standardization (ISO), International Electrotechnical Commission (IEC), International Hydrographic Organization (IHO), International Telecommunication Union (ITU) and other related organizations are expected to work on standardization in a simultaneous manner. In addition, proactive support of international society is required, including the holding of international fora, seminars or workshops on MASS to enable a balanced collection of multi-stakeholder opinion in the process of amending Conventions and developing new regulations as well as new technical standards.

4.2. Maritime Safety
By the time when MASS is introduced and practically operated, new risk factors are expected to emerge such as threats against cyber security and errors in advanced automation systems. In this regard, it is a prerequisite to amend existing Conventions and/or develop new regulations after reviewing RSE. At the same time, international society needs to engage in discussion on the following issues considering the trends of digitization and automation to enhance the safety of MASS:

- Developing safety assessment guidelines by degree of autonomy of MASS.
- Improving cyber security guidelines for various stakeholders including ports as well as ships.
- Reinforcing international cooperation programs for the capacity-building including training and education aimed at ensuring safe operation of MASS, especially focused on developing countries.
- Considering reasonable methods to improve Customs, Immigration and Quarantine procedures given that MASS is without human interaction.

4.3. Legal Issues
As mentioned above, legal controversy emanating from MASS may arise in relation to the United Nation Convention on the Law of the Sea (UNCLOS) as well, most likely in that coastal States will find it difficult to secure effectiveness of legal action in the process of exercising jurisdiction. Hence, potential legal issues in relation to UNCLOS should be widely reviewed.

4.4. Training and Education
In the interest of achieving effectiveness in introducing and operating MASS, it would be imperative to nurture expert personnel capable of operating MASS above all. Especially, in-depth consideration should be given to the qualification of remote control operators on shore who will control MASS on shore. Remote control operators on shore need to be equipped with the basic capability required from seafarers as per the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW). If needed, the option of adding new qualification criteria or KUP in STCW should be considered. Moreover, international society should look for ways to expand support to developing countries.

4.5. Ethical Concerns
Ethical issues also need to be reviewed. It should be ensured that ethical/moral judgment of humans is not undermined due to overdependence on technology. Even if ships are operated from shore, moral hazard, under which maritime accidents are taken lightly must be checked against with vigilance. Furthermore, a range of ethical concerns need to be considered, including the difficulty of human-machine communication, scope of delegating machines with decision-making authority and privacy protection. International society should also deliberate ways to come up with ethical norms, which multiple stakeholders such as manufacturers, owners and remote control operators on shore of MASS need to comply with.

5. Conclusion
This paper presents the key findings and recommendations from technology assessment which has been carried out in order to provide useful guideline for policymakers and contribute to forming social discourse surrounding MASS. Key findings are as follows:

- Shipping and port industries form a complex and dynamic ecosystem where numerous stakeholders participate. Communication and collaboration among diverse members of society are highly needed to ensure safe, effective and efficient introduction and operation of MASS.

- Although the current main cause of maritime accidents is human error which takes account for about 79% of entire maritime accidents in ROK, the introduction of MASS is predicted to change the causes of maritime accidents. Six types of potential new risk factors are also proposed.

- The concept of the ship is expected to change. As human seaworthiness is reduced going forward with MASS, ships may gradually transform into active agents that make small and big decisions to achieve safety and efficiency of navigation. Considering the UNCLOS with MASS, legal controversy can emerge due to the difficulty of securing effectiveness of enforcement when coastal states exercise jurisdiction.

- Concerns and optimistic expectations on jobs coexist. Although the number of seafarers’ job can decline, quality of jobs can improve and MASS can create new and attractive jobs in the future. Also, since on-shore operators of MASS should have basic knowledge and skills of navigation including the case of emergency situations, it is important to develop proper qualification standards.

- Ethical issues related to MASS are expected to be widely raised and should be dealt in a serious manner. Despite the difficulty of finding universal solutions as with the trolley dilemma, tackling such issues will be significant given that humans will delegate big and small decisions to ships and autonomous systems in the future. Especially, the moral hazard of taking maritime accidents lightly should be prevented as the safety of seafarers will be separated from that of ships by MASS.
- MASS is expected to bring about a shift in the liability structure regarding maritime accidents. The liability of manufacturers would increase compared to conventional manned ships. The public benefit of accommodating MASS and allowing swift remedy for victims should be considered in a balanced way, in the process of setting reasonable criteria and scope on liability between shipowner and manufacturer.

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