Navigation Safety and Risk Management Verification Mechanism for Maritime Autonomous Surface Ship (MASS)

Received: May 30, 2025
Revised: June 18, 2025
Accepted: June 26, 2025

Po-Chih Chiu[1] Shun-Ming Chang[2*] Pai-Lung Chou[3]
[1] Guangzhou institute of Science and Technology, Guangzhou
[2] College of Management, National Kaohsiung University of Science and Technology, Kaohsiung, Taiwan
[3] Department of Risk Management and Insurance, National Kaohsiung University of Science and Technology, Kaohsiung, Taiwan
[*]diego7099@gmail.com

Abstract

The development of Maritime Autonomous Surface Ships (MASS) has attracted the attention of the maritime industry. However, people hope to reduce the risk of human error through relevant technologies, but the process of technological verification will give rise to other related problems. This study hopes to effectively curb the spread of risks through a set of management mechanisms and effectively assess and improve the problems derived from risks. Through the mechanism to ensure the impact of the verification process of the relevant functions of MASS on the current actual maritime operating environment (including autonomous and remote-control navigation). This study, through this iterative verification mechanism, controls risk within an acceptable range and collaborates with cross-disciplinary experts and scholars to examine the potential risk issues that the innovation process poses to both internal and external environments. As these issues are collected, the relevant supervisory authorities can evaluate and modify the current operational norms and legal and regulatory requirements through these empirical experiences. The research results provide an effective and systematic empirical verification mechanism for introducing innovative technology in the future society.

Keywords: Maritime Autonomous Surface Ship (MASS); Navigation safety; Risk management; Verification mechanism

1. Introduction

Maintaining the safety of life and property at sea and protecting the marine environment are the primary goals in the maritime field. Through the power of technological innovation, we continue to update the technologies required for operations in the maritime field. "Global Marine Technology Trends 2030" has confirmed that "Smart Ship" is a key technology for the development of the maritime field, especially autonomous navigation and control as the core of the technology (Shenoi et al., 2015). Countries have also begun to invest huge resources in formulating related plans, including the world's first "FALCO" fully autonomous sailing test completed by Rolls-Royce Marine in 2018 (Rolls-Royce, 2018), Japan and South Korea are also working hard for the upcoming era of autonomous sailing ships (Enevoldsen et al., 2023;

Nguyen et al., 2022). The International Maritime Organization (IMO) officially proposed the concept of Maritime Autonomous Surface Ship (MASS) at the 99th meeting of the Maritime Safety Committee (MSC). At the 101st meeting, MSC issued the "Interim Guidelines for Testing of Autonomous Maritime Surface Navigation Ships" and approved MASS to conduct actual testing in actual sea areas under restricted conditions (IMO, 2018). However, the guidelines retain details such as flexibility and technical specifications required in the test execution process in accordance with the maritime culture, climate environment, technical capabilities and other factors of each country.

Taiwan established the "Unmanned Vehicle Technology Innovation Ordinance" in 2018 to use the innovative spirit of sandbox supervision to encourage industry, government, academia and research to invest in the research and development and application of unmanned vehicles through loosening regulations to promote industrial technology development and innovation. In 2019, the Kaohsiung City Steamship Company cooperated with the Ship and Marine Industry Research and Development Center (hereinafter referred to as the Ship Center) to transform the original electric ferry (Love Boat) into Taiwan's first and stern intelligent surface unmanned vehicle in Love River Bay (Figure 1). Through the empirical research of the above-mentioned plans, relevant R&D units will be able to think about the regulations and standards, technological innovation trends, safety and risk management and other issues that they will face in the future development of MASS.

Figure 1

Taiwan's Autonomous Surface Navigation Fleet Piloted in 2019 - Results of the Love Boat Research Project

**Source: https://kcs.kcg.gov.tw/Content_List.aspx?n=38E3F0AC78634C4C*

2. Literature Review

This study divides the past efforts of experts and scholars from various countries on the development of MASS into three parts: (1) regulations and guidelines (2) development and innovation of ship autonomous navigation and remote-control technology (3) empirical research on MASS.

2.1 Regulations and Guidelines

IMO organized the MSC 108 meeting to develop the "Management Charter for Maritime Autonomous Navigation Ships on the Surface" (MASS Code) during the adjournment. The main functions of the development are divided into an introduction (Introduction), operating environment, and functional requirements (Main Principles for MASS and MASS Functions). and three main charter structures: Goals, Functional Requirements, and Provisions. In the third charter, the main functions of MASS are distinguished, including 17 main development functions such as navigation and remote operations. At the same time, it also confirms the International Convention for the Safety of Life at Sea (SOLAS), the International Regulations for Preventing Collisions at Sea (COLREG), and the International Seafarer's Watch. Norms such as the Standards for Training and Certification of Watchkeepers (STCW) are applicable to MASS. IMO member countries will review the scope of national regulations and take into account the definition of regulatory scope (Regulatory Scoping Exercise, RSE) (International maritime organization, 2018a, 2018b). Countries have also conducted in-depth assessments of future practical application scenarios in the maritime environment for these 17 functions. This research mainly focuses on the functional development and verification of two main functions, including navigation and remote control (Report of the Intersessional MASS Working Group, 2023).

The American Bureau of Shipping (ABS) revised the "Autonomous and Remote-Control Functional Requirements" from the original design guide (Guide) to specification requirements (Requirements) in 2022, which not only provides the industry with testing and verification of ship-related functions, but also It also represents changing the original non-mandatory recommendations into mandatory verification requirements (ABS, 2022). China Classification Society (CCS) will publish the "Guidelines for the Inspection of Class Notations for Autonomous Navigation of Ships" in 2023 (CCS, 2023). The guidelines set out the performance requirements for autonomous navigation functions and propose verifiable and followable processes for the development, design and management of the system. Architecture. Japan and South Korea also put forward relevant project plans and specification requirements (Class NK, 2024; KR, 2024). From the process of project planning and specification development in various countries, we can know how each country identifies autonomous navigation systems. However, when examining the current entry and exit procedures of various countries, the question that arises is how to integrate MASS into the current maritime operating environment, including the entry and exit procedures of ocean-going ships and the impact of other operating vessels in the environment on the premise of considering navigation safety. influence and meet the trend needs of intelligence and automation.

2.2 Development and Innovation of Ship Autonomous Navigation and Remote-Control Technology

The European Maritime Safety Agency (EMSA) investigated accidents between 2014 and 2022. Nearly 59.1% of accidents involved human factors, of which 50.1% were related to human behavior. A comprehensive analysis of human behavior and influencing factors shows that the proportion of human factors in these accidents is as high as 80.7% (Annual Overview of Marine Casualties and Incidents 2023, 2023). In addition, the development of autonomous navigation technology can help solve the following four problems: (1) respond to the harsh maritime environment and alleviate the future shortage of seafarers, (2) reduce overall transportation operating costs, (3) reduce carbon emissions in response to global environmental changes platoon needs, (4) the need to improve navigation safety (Porathe et al., 2014). Therefore, it is crucial to use autonomous navigation and increase decision-making assistance through remote control technology as a solution to reduce maritime accidents and improve related operational issues. The following describes the research related to ship autonomous navigation and remote control:

2.2.1 Autonomous Navigation

According to the ABS "Autonomous and Remote-Control Functional Requirements", an intelligent assisted navigation stage (intelligentization) must be passed before fully autonomous navigation (ABS, 2022). The use of information and communication equipment to assist navigation ships increases their awareness of the environment, such as the impact of bridge piers on water flow during navigation, which may increase the possibility of ship collisions and affect the safety of ship navigation (Geng et al., 2023); in inland shallow waters, reduce the risk of stranding of sailing ships due to tides (Picado et al., 2022). Although the development of MASS-related technologies is expected to reduce potential risks caused by human factors and bring many benefits (Norris, 2018), there are also many operational-related challenges, such as the large demand for ship sensors. The data processed (Wahlström et al., 2015), or in the future, the MASS operator may remotely control the ship without being on the ship, so there is a risk of delays or limitations in the ship's situational awareness, which will affect the Ship maneuverability (MacKinnon et al., 2015).

The autonomous navigation of ships in the maritime environment and the autonomous driving of vehicles on the road have completely different navigation safety factors to consider. Autonomous sailing ships need to consider the encounter situations with other autonomous sailing ships or traditional ships. How to evaluate the possibility of avoiding collision or stranding at sea through complex power propulsion systems without a visible channel. The process needs to combine the real-time ship situation and the maritime environment. A feasible short-term proposal is to use personnel to assist autonomous navigation ships and establish an information exchange mechanism between ships (Kim et al., 2023; Maidana et al., 2023; Rødseth et al., 2023; Zheng et al., 2024). However, for fully autonomous navigation, complex system evaluation methods must still be adopted, combining the three basic technologies of situation awareness, collision risk detection and intelligent assisted decision-making (Chen et al., 2020; Wang et al., 2024).

2.2.2 Remote Control

The description of the remote-control function defined by IMO in the "Regulations on the Management of Autonomous Ships Navigating Maritime Surface Navigations" believes that MASS or automation functions should be able to be controlled from a safe remote operating center (the Remote Operating Center, ROC). During the process, there should be a verified and verifiable system operation interface between ROC and MASS to ensure that MASS can maintain safe, reliable, and effective operation when used.

IMO highlighted the gaps in regulatory experience regarding the role of remote operators during the current development stage of the MASS program. It is believed that the role of the ROC operator and its related operational management issues are listed as the most high-priority issues that need to be resolved at this stage (IMO, 2021). At the same time, people are also worried that although humans hope to use artificial intelligence to enhance the decision-making capabilities of crew members and remote operators, highly complex decision support systems are difficult to understand and opaque for crew members and remote operators, which may cause difficulty in decision-making during human-computer interaction (MacKinnon et al., 2015).

2.3 MASS-Related Empirical Research

Among the previous documents, most of them are the results of the completed MASS project. This section mainly introduces the current international MASS projects that are being developed in various countries. Compared with the period from 2020 to 2023, most countries have invested in the development of autonomous navigation and remote-control functions. The current development directions of major projects in various countries are slightly different, which also means that various countries have more imaginable possibilities for their future expectations for MASS. The U.S. ABS will release the "Guide for Smart Functions for Marine Vessels and Offshore Units" and the "Guide for Smart Technologies for Shipyards" in 2023, integrating the application of artificial intelligence technology into Extending from ships to offshore facilities and shipyards. Through artificial intelligence, the relevant production and maintenance work processes of offshore facilities and shipyards are combined, and augmented reality technology is combined to assist maintenance personnel in equipment maintenance (ABS, 2023a, 2023b). The Maritime and Port Authority of Singapore (MPA) will release the Just in Time Planning and Coordination Platform (JIT Platform) combined with smart ports in 2023. It is hoped that through automated planning and operation processes, the waiting time for ships to enter and exit the port will be reduced, thereby reducing the problem of carbon emissions during the waiting process. At the same time, it also reduces the risk of personal injury caused by crew members traveling between the ship and the port due to the operation process (MPA, 2023). The EU hopes to effectively alleviate land traffic congestion through autonomous navigation of inland waterways and reduce air and noise pollution problems.

In addition to the research project reports of the above-mentioned countries, in international academic research, attention is also paid to the development of MASS-related technologies. Research from Chinese scholars assesses the complexity of navigation missions through the TOPSIS method (Tao et al., 2025). Also from China, the research conducts navigation collision avoidance decisions through quantitative analysis of the ship's attitude and autonomous navigation environment detection (Shi et al., 2025). Since the immediate changes in the Marine environment during navigation are closely related to the ship's navigation decisions, the decision on the ship's draft is controlled by detecting the changes in navigation and environmental conditions in real time through an adaptive approach (Yan et al., 2024). Research from South Korea uses the detection of ship trajectories to make ship navigation decisions for collision avoidance (Lee & Kim, 2025). Scholars have clearly pointed out that there are many potential risk issues during the autonomous navigation of ships, including cyber-attacks, human errors, and equipment malfunctions, among other navigation risk problems that cannot be ignored (Chang et al., 2021). By integrating the project results and academic research achievements of the above-mentioned countries, although it can be known that the development of autonomous navigation technology and the importance of risk management in navigation decision-making are significant, there are few studies discussing the integration of technology development and actual Marine environment verification mechanisms to assist management units in conducting risk assessment and verification.

Compiling the above-mentioned research results of autonomous maritime navigation ships and smart ship projects in various international countries, we can understand that various countries have invested huge resources in the development of related technologies. It is hoped that artificial intelligence-related applications will be integrated into the maritime environment to solve existing problems in the maritime operating environment. However, the risk management issues hidden in current operations due to the introduction of innovative technologies cannot be ignored. Therefore, this study proposes the navigation safety and risk management verification mechanism for autonomous water navigation ships and functions in the next section, hoping to reduce the impact on the existing operating environment caused by the introduction of innovative technologies.

3. Navigation Safety and Risk Management Mechanism for Autonomous Maritime Navigation Ships and Functions

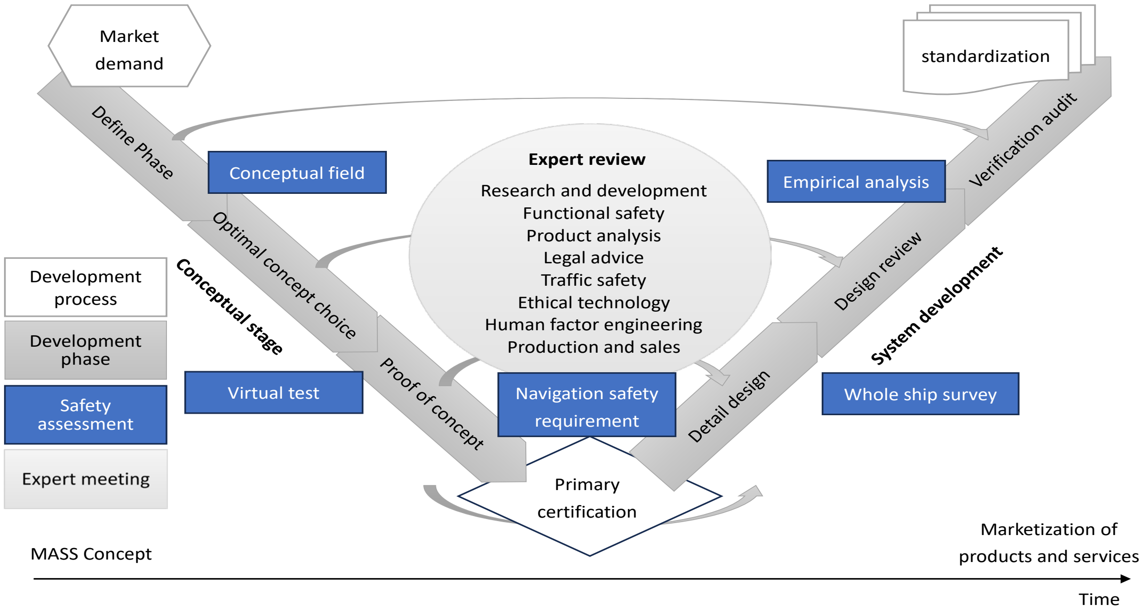
3.1 The Verification and Validation Testing of Systems Engineering

The verification mechanism proposed in this study originates from the project management concept of systems engineering (Forsberg & Mooz, 1991). Such a concept is widely applied in the development of autonomous driving technology for automobiles (ISO 26262) (Dawson & Garikapati, 2021), and Model Based Systems Engineering (MBSE) (Henderson & Salado, 2021). The core technologies of systems engineering in automotive autonomous driving technology have not changed much over the past few years, but the complexity will grow and increase exponentially with the scale of the system. Meanwhile, the autonomous navigation technology of ships is significantly different from that of self-driving cars. During the navigation of a ship at sea, it cannot obtain immediate feedback and stop the ship through the friction of the road surface like a car's braking system. It must have a longer reaction time to avoid the occurrence of sea collision accidents. The navigation decisions of MASS in the port area require support from multiple parties, including the assistance of the crew, the maritime pilot and the control tower, in order to navigate and dock safely. How to verify the results of system integration will be a verification issue for complex systems (Tang et al., 2025). Therefore, it is necessary to re-examine the risks that autonomous navigation technology may bring during the field measurement process and establish a verification mechanism for risk control. It is hoped that through the management of the mechanism and continuous iterative testing, the losses and impacts caused by risks can be improved and reduced.

This study suggests that relevant R&D projects can be divided into two main stages: the concept stage and the system development stage. The concept stage mainly focuses on MASS and related functional hazard risk analysis through market demand analysis. The development process can be subdivided into the definition stage, the best concept selection stage and the concept verification stage; the system development stage mainly focuses on security verification, and it is expected to standardize future products and services through the development process. The development process can be subdivided into detailed design time, design review stage and verification sign-off nuclear stage. During the process, a cross-field expert team needs to jointly confirm the navigation safety requirements in the maritime operating environment. The cross-domain expert team includes internal experts on navigation safety, system functions, human factors engineering, product services and regulatory compliance analysis, as well as navigation safety, market competition analysis, cognitive psychology, laws and regulations outside the project, ethics and other external experts to jointly review the development results of relevant functional requirements (Figure 2).

Figure 2

Risk Management Verification Mechanism for Autonomous Navigation and Remote-Control Functions



**Noted: generated by researchers*

This verification mechanism not only ensures the risk management issues caused by innovative technology development in the actual field-testing process but also hopes to connect internal and external experts through the development process to jointly examine the impact of relevant technologies on the internal and external environment. For the internal environment, the main assessment is to examine compliance with overall project requirements. As for the external environment, it mainly examines the impact of innovative technologies on the future market environment, while confirming compliance with laws and regulations. If necessary, amendments to relevant bills need to be proposed (such as regulations and requirements related to entry and exit application notification procedures). In addition, as MASS technology matures, the relevant personnel operating environment on the ship needs to be adjusted in response to operational needs. In addition, internal and external experts are also alert to the navigation safety risks that network information security may pose to MASS.

3.2 The Experience and Feedback Obtained Through Empirical Research

This study divides the feedback obtained during the testing process into the external environment and the internal operating system for separate description, hoping to provide the necessary experience and information for future related research.

3.2.1 Reduce the Complexity of Management Through Iterative Environment Testing

In the part of the external environment, this study conducts an empirical review in combination with an expert team and holds that the construction of infrastructure will affect the development of autonomous navigation systems. The so-called construction of infrastructure includes issues related to network communication and network security. The decision-making process for ship navigation requires multi-party communication and coordination among crew members, navigators and port control towers. Therefore, a smooth network communication connection is highly necessary. In the empirical process, our research team adopted 5G technology for network communication connection. During the testing process, a network latency issue occurred (though it lasted for a short period of time, about a few seconds). The crew members reported that especially during the process of the vessel docking, this delay of just a few seconds could very likely lead to incorrect operation and pose a risk of vessel collision. Although, this problem is expected to be improved in the future through satellite communication and 6G network technology. But at this stage, it remains an important issue of concern for the research team.

3.2.2 Reduce the Complexity of Systems Engineering Through Iterative System Testing

In the part of internal system construction, most project teams divide the autonomous navigation system into multiple subsystems such as environmental sensing, navigation decision-making and navigation control for development. And each subsystem will have distinct system differences due to the different technologies adopted. With environmental sensing technology, traditional ships rely on the AIS system to detect the ship's navigation trajectory. However, the AIS system has a time difference problem. Therefore, environmental sensing technology needs to integrate perception technologies of the real environment, such as radar and machine vision. However, when considering the complexity of system engineering, independent verification is required before conducting system integration testing. Enable system developers to obtain actual information from the actual testing process to confirm and verify whether the system development conforms to the expected Settings.

3.2.3 Human-Machine Collaboration and Personnel Training Issues

The long-term goal of setting up the autonomous navigation system is to reduce the potential human errors that may occur during the operation of the ship crew during navigation. However, according to the current regulatory requirements, during the operation process of the autonomous navigation system, the crew members still have to obtain relevant information about the system decision-making process through the display and be responsible for the navigation safety decision-making. Such navigation operation tasks require a high degree of human-machine collaboration. However, this is significantly different from the traditional navigation operation environment of maritime personnel. Therefore, before the introduction of the autonomous navigation system, there must be a meticulous personnel training mechanism. Through various navigation mission training operations, the crew members can become familiar with how to carry out collaborative cooperation. The expert team suggests that the relevant management units establish corresponding personnel training institutions to combine with the actual navigation mission operations, which will be conducive to the collaborative cooperation of multiple parties.

4. Conclusion

The commissioning of autonomous sea navigation ships and the development of related functions provide more possibilities and choices for the current harsh maritime operating environment. This means that many systems will be jointly developed to perform operations that humans have performed in the maritime environment through automation (autonomous functions). At the same time, it will also face the integration of functional systems such as navigation systems, communication systems, passenger and cargo transportation systems, and shore-side traffic control centers. This study proposes a systematic verification mechanism through empirical research to establish internal and external experts and scholars who can collaborate across fields to reduce the impact of the introduction of innovative technologies on the current operating environment.

References

ABS. (2022). *Requirements for Autonomous and Remote-Control Functions. American Bureau of Shipping.* https://ww2.eagle.org/en/rules-and-resources/rules-and-guides-v2.html

ABS. (2023a). *Guide for Smart Functions for Marine Vessels and Offshore Units.* https://ww2.eagle.org/content/dam/eagle/rules-and-guides/current/other/307-guide-for-smart-functions-for-marine-vessels-and-offshore-units-2023/307-smart-guide-dec23.pdf

ABS. (2023b). *Guide for Smart Technologies for Shipyards.* https://ww2.eagle.org/content/dam/eagle/rules-and-guides/current/other/336-guide-for-smart-technologies-for-shipyards/336-smart-yard-guide-feb23.pdf

Annual Overview of Marine Casualties and Incidents (2023). *European Maritime Safety Agency.* https://www.emsa.europa.eu/publications/reports/item/5052-annual-overview-of-marine-casualties-and-incidents.html

CCS. (2023). Guidance on Survey of Autonomous Navigation Notations. https://www.ccs.org.cn/ccswz/specialDetail?id=202304200978368142

Chang, C.-H., Kontovas, C., Yu, Q., & Yang, Z. (2021). Risk assessment of the operations of maritime autonomous surface ships. *Reliability Engineering & System Safety,* 207, 107324. https://doi.org/https://doi.org/10.1016/j.ress.2020.107324

Chen, Z., Chen, D., Zhang, Y., Cheng, X., Zhang, M., & Wu, C. (2020). Deep learning for autonomous ship-oriented small ship detection. *Safety Science,* 130, 104812. https://doi.org/https://doi.org/10.1016/j.ssci.2020.104812

ClassNK. (2024). *Rules for Automatic and Remote-Control Systems / Guidance.* https://www.classnk.or.jp/hp/en/rules/tech_rules.aspx

Dawson, J., & Garikapati, D. (2021, April). *Extending ISO26262 to an operationally complex system.* In 2021 IEEE International Systems Conference (SysCon) (pp. 1-7). IEEE. https://ieeexplore.ieee.org/abstract/document/9447146/

Enevoldsen, T. T., Blanke, M., & Galeazzi, R. J. I.-P. (2023). Autonomy for ferries and harbour buses: A collision avoidance perspective. *IFAC-Papers OnLine,* 56(2), 5735-5740.

Forsberg, K., & Mooz, H. (1991). The relationship of system engineering to the project cycle. *Center for Systems Management,* 5333. https://damiantgordon.com/Methodologies/Papers/The%20Relationship%20of%20System%20Engineering%20to%20the%20Project%20Cycle.pdf

Geng, Y., Guo, M., Guo, H., & Chen, H. (2023). Safety range in bridge areas based on the influence of cross flow on ship navigation. *Ocean Engineering,* 281, 114649. https://doi.org/https://doi.org/10.1016/j.oceaneng.2023.114649

Henderson, K., & Salado, A. (2021). Value and benefits of model‐based systems engineering (MBSE): Evidence from the literature. *Systems Engineering, 24*(1), 51-66.

IMO. (2018). IMO takes first steps to address autonomous ships. International Maritime Organization. https://www.imo.org/en/MediaCentre/PressBriefings/Pages/08-MSC-99-mass-scoping.aspx

IMO. (2021). *Outcome of the Regulatory Scoping Exercise for the Use of Maritime Autonomous Surface Ships (MASS).* https://www.imo.org/en/MediaCentre/PressBriefings/pages/MASSRSE2021.aspx

International maritime organization, I. (2018a). *MSC 99/5 - REGULATORY SCOPING EXERCISE FOR THE USE OF MARITIME AUTONOMOUS SURFACE SHIPS (MASS).*

Maritime Safety Committee, London, UK.

International maritime organization, I. (2018b). *MSC 100/INF.3 - REGULATORY SCOPING EXERCISE FOR THE USE OF MARITIME AUTONOMOUS SURFACE SHIPS (MASS).* Maritime Safety Committee, London, UK.

Kim, D., Yim, J., Song, S., Park, J.-B., Kim, J., Yu, Y., Elsherbiny, K., & Tezdogan, T. (2023). Path-following control problem for maritime autonomous surface ships (MASS) in adverse weather conditions at low speeds. *Ocean Engineering,* 287, 115860. https://doi.org/https://doi.org/10.1016/j.oceaneng.2023.115860

KR. (2024). Guidance for Autonomous Ships. Korean Register. https://www.krs.co.kr/KRRules/KRRules2024/KRRulesE.html

Lee, H.-J., & Kim, D. (2025). Navigating narrow waterways: A quantitative study on timing of stand-on ship actions for cooperative collision avoidance for MASS. *Ocean Engineering,* 322, 120400. https://doi.org/https://doi.org/10.1016/j.oceaneng.2025.120400

MacKinnon, S. N., Man, Y., Lundh, M., & Porathe, T. (2015). *Command and control of unmanned vessels: Keeping shore based operators in-the-loop.* 18th International Conference on Ships and Shipping Research, NAV,

Maidana, R. G., Kristensen, S. D., Utne, I. B., & Sørensen, A. J. (2023). Risk-based path planning for preventing collisions and groundings of maritime autonomous surface ships. *Ocean Engineering,* 290, 116417. https://doi.org/https://doi.org/10.1016/j.oceaneng.2023.116417

MPA. (2023). *MPA IMPLEMENTS JUST IN TIME PLANNING AND COORDINATION PLATFORM.* https://britanniapandi.com/2023/11/mpa-implements-just-in-time-planning-and-coordination-platform/

Nguyen, T. T. D., Mai, V. T., Lee, S., & Yoon, H. K. (2022). An Experimental Study on Hydrodynamic Forces of Korea Autonomous Surface Ship in Various Loading Conditions. *Journal of Navigation and Port Research, 46*(2), 73-81. https://koreascience.kr/article/JAKO202214049471881.page

Norris, J. N. (2018). *Human Factors in Military Maritime and Expeditionary Settings: Opportunity for Autonomous Systems?*. In Advances in Human Factors in Robots and Unmanned Systems: Proceedings of the AHFE 2017 International Conference on Human Factors in Robots and Unmanned Systems, July 17− 21, 2017, The Westin Bonaventure Hotel, Los Angeles, California, USA 8 (pp. 139-147). Springer International Publishing.

Porathe, T., Prison, J., & Man, Y. (2014). *Situation awareness in remote control centres for unmanned ships.* Proceedings of Human Factors in Ship Design & Operation, 26-27 February 2014, London, UK,

Rødseth, Ø. J., Wennersberg, L. A. L., & Nordahl, H. (2023). Improving safety of interactions between conventional and autonomous ships. *Ocean Engineering,* 284, 115206. https://doi.org/https://doi.org/10.1016/j.oceaneng.2023.115206

Rolls-Royce, K. (2018). *Rolls-royce and finferries demonstrate world's first fully autonomous ferry.* https://www.rolls-royce.com/media/press-releases/2018/03-12-2018-rr-and-finferries-demonstrate-worlds-first-fully-autonomous-ferry.aspx

Shenoi, R., Bowker, J., Dzielendziak, A. S., Lidtke, A. K., Zhu, G., Cheng, F., Argyos, D., Fang, I., Gonzalez, J., & Johnson, S. (2015). Global marine technology trends 2030.

Shi, P., Gao, M., Chen, S., Jing, Q., Xia, Y., Han, Y., & Zhang, A. (2025). MASS intelligent collision avoidance decision-making based on ship pose estimation and COLREGs quantification. *Ocean Engineering,* 335, 121679.

https://doi.org/https://doi.org/10.1016/j.oceaneng.2025.121679
Tang, Y., Yang, C., Xia, Y., Cao, L., & Zhang, J. (2025). Towards MASS: A concept and a framework for operating only once of electromechanical devices on ocean-going merchant vessels. *Ocean Engineering, 330,* 121319. https://doi.org/https://doi.org/10.1016/j.oceaneng.2025.121319
Tao, J., Liu, Z., Wang, X., Wang, J., Rao, S., & Yang, Z. (2025). Team task complexity analysis in MASS operation using a fuzzy TOPSIS method. *Ocean Engineering,* 329, 121140. https://doi.org/https://doi.org/10.1016/j.oceaneng.2025.121140
Wahlström, M., Hakulinen, J., Karvonen, H., & Lindborg, I. (2015). Human Factors Challenges in Unmanned Ship Operations – Insights from Other Domains. *Procedia Manufacturing, 3,* 1038-1045. https://doi.org/https://doi.org/10.1016/j.promfg.2015.07.167
Wang, C., Cai, X., Li, Y., Zhai, R., Wu, R., Zhu, S., Guan, L., Luo, Z., Zhang, S., & Zhang, J. (2024). Research and Application of Panoramic Visual Perception-Assisted Navigation Technology for Ships. *Journal of Marine Science and Engineering, 12*(7).
Yan, Z., Wang, H., & Zhang, M. (2024). Learning-based adaptive neural control for safer navigation of unmanned surface vehicle with variable mass. *Ocean Engineering,* 313, 119471. https://doi.org/https://doi.org/10.1016/j.oceaneng.2024.119471
Zheng, K., Zhang, X., Wang, C., Li, Y., Cui, J., & Jiang, L. (2024). Adaptive collision avoidance decisions in autonomous ship encounter scenarios through rule-guided vision supervised learning. *Ocean Engineering, 297*, 117096. https://doi.org/https://doi.org/10.1016/j.oceaneng.2024.117096