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Legal Challenges of Maritime Autonomous Surface Ships: A Comparative Study of Neighboring States and Implications for Vietnam

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Abstract: International Maritime Organization and countries have been paying special attention to Maritime Autonomous Surface Vessels (MASS). MASS is assessed to be able to bring benefits to the world maritime industry, but it also raises legal issues that need to be further studied and improved. Countries in the region have many activities related to MASS, typically issuing MASS standards, building MASS test sea areas, smart ports, sandboxes, etc. This study analyzes and evaluates in detail the policies, strategies and regulations of some typical countries in the region on MASS. In addition, the article also analyzes and synthesizes the current regulations of international conventions, whether or not they are suitable for MASS. From that analysis, the article presents experiences for Vietnam as well as other countries in the region to shorten the time to build and improve regulations for MASS. Develop action strategies for the construction, testing and development of MASS in practice. At the same time, the article also emphasizes the need to further strengthen regional cooperation in the ASEAN region.

Keywords: Legal framework, maritime autonomous surface ships, maritime law, MASS policy.

1. INTRODUCTION

The rapid development of digital technology and artificial intelligence (AI) in the context of the Fourth Industrial Revolution is gradually reshaping the global maritime industry. One of the most evident manifestations of this process is the development of Maritime Autonomous Surface Ships (MASS). Similar to autonomous land vehicles or drones, autonomous vessels are increasingly attracting the attention of organizations, countries, and shipping companies. In 2018, the International Maritime Organization (IMO) officially used the term MASS and began discussions on the necessary legal and regulatory adjustments for MASS.

The emergence of MASS raises many questions regarding how to classify and manage them. The IMO has provisionally proposed four levels of autonomy, and the review and refinement of standards are still ongoing. Despite rapid technological advancements, current AI capabilities cannot fully replace the judgment and problem-solving abilities of seafarers in emergency situations. Therefore, research and development efforts are prioritizing the automation of routine operations, while humans remain crucial in handling incidents and unexpected situations.

Alongside technological progress, MASS also presents numerous legal and policy challenges. These include: legal liability, compliance with existing maritime conventions, cybersecurity, the legal status of remote operators, and requirements related to maritime safety and marine environmental protection. Countries such as Singapore, China, South Korea and Japan have proactively developed national strategies, regulations, and standards related to MASS, established test sites, developed management mechanisms, supported testing, implemented experimental MASS, and enacted legislation. The experiences of these countries provide important reference value for Vietnam, which is now beginning to research and develop a policy framework in this field.

1.1. Reasons for research

In Vietnam, research on MASS governance is essential. MASS has been and continues to be a focus of research by the IMO and countries in the region, while in Vietnam, readiness to research and develop MASS is still in its early stages, and there are no policies or orientations for MASS. Currently, only a few studies on MASS have been conducted by individuals and research groups [1], [2]. On a global scale, studies conducted in

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Research article

recent years have shown that MASS can bring many benefits to the maritime industry. However, they have also revealed shortcomings in the legal system built for manned vessels. Timely and comprehensive assessment of these issues is crucial to ensuring that the national legal system can adapt to the transformation in maritime transport and maintain compatibility with international trends.

1.2. Research methodology

The research primarily uses qualitative analysis, assessment, and comparison methods, including:

Analysis of several IMO and MASS conventions;

Research and analysis of the legal policies and strategies of Singapore, China, South Korea and Japan. The selection of these countries for study can be summarized by the following key points:

Initially, these countries play a leading role in the region in the development and governance of MASS and have actively participated in both domestic regulatory testing and international norm-setting. Their experience provides valuable insights into how national legal systems address the legal gaps identified through the IMO’s Regulatory Scope Review (RSE) Programme.

Furthermore, the selected countries reflect different governance models and legal strategies, allowing for meaningful analysis and comparison. Singapore exemplifies a “legal sandbox” approach, with MASSport characterized by flexibility, close collaboration between regulatory bodies and industry, and early operational trials in port management. China represents a large-scale, state-led policy and industry model, integrating MASS development into broader national strategies on digitalization and intelligent transport. South Korea pursues a phased, risk-managed approach, combining strong shipbuilding capabilities with gradual legal adjustments and government-funded pilot projects. In contrast, Japan demonstrates a technology-based approach that prioritizes conventions, emphasizing safety and consistency with existing international maritime conventions. These aspects will be analyzed in detail in section 3 of this article.

Thirdly, these countries share significant structural similarities with Vietnam, being maritime-oriented coastal states heavily reliant on shipping and port services, while differing significantly in institutional capacity, technological readiness, and the level of legal development and development. Notably, countries like Japan, South Korea, and China all belong to the same civil law system as Vietnam; furthermore, China has a legal system structure quite similar to Vietnam’s. In contrast, Singapore’s common law system is considered a diverse option for comparison and evaluation of the development and refinement of the legal framework for MASS. This combination allows Vietnam to assess not only best practices but also legal pathways at each stage, consistent with a developing maritime legal system.

Finally, at the regional level, these countries reflect Asia’s growing influence in shaping global MASS governance. Given the density and complexity of the legal landscape of Southeast Asia, Vietnam’s future MASS framework will depend not only on compliance with IMO instruments but also on the ability to interact with regulations and coordinate policies with countries in the region.

Synthesis of academic literature and research related to MASS in Vietnam;

Analysis of some current Vietnamese regulations related to MASS.

1.3. Research structure

The paper begins by introducing the concept and classification of MASS. The following section analyzes some legal issues in the relationship between MASS and several important international conventions. The focus of the research is the analysis of the legal policies and strategies for MASS development in Singapore, China, and South Korea. The final section draws lessons learned and proposes directions for Vietnam and other countries in the region.

1.4. Main results

Comparative analysis shows that technological readiness is progressing rapidly, but the level of sophistication of regulatory mechanisms differs significantly between countries. Singapore’s sandbox model, China’s large-scale industrial legal policy, and South Korea’s and Japan phased trial approach represent different paths in MASS research and development. These experiences highlight Vietnam's need to build a flexible legal strategy, delineate responsibilities among agencies, units, and businesses, and actively participate in international standardization processes within the IMO framework.

2. CONCEPT OF MASS AND RELATED LEGAL ISSUES

2.1. Concept of maritime autonomous surface ships

The IMO officially uses the term Maritime Autonomous Surface Ships to describe ships that operate with varying levels of automation, from those needing human supervision to those functioning completely without human input. The IMO uses the term “Surface Ships”; however, in the shipbuilding industry in some countries, other terms such as “Smart ships”, “Autonomous ships”, and “Unmanned ships” are currently being used interchangeably.

IMO describes the levels of automation and human interaction on board ship [3], from level 1 (human-controlled ships with automated processes) to level 4 (fully automated, ships operating without human intervention). The four levels are: Level 1 with automated processes and decision support, Level 2 with remote control but crew on board, Level 3 with remote control and no crew on board, and Level 4 is fully automated.

In addition to the IMO’s four-level classification, certain countries and organizations have adopted different approaches. For example, the United States Department of Transportation defines the levels of automation based on the involvement of machinery and the interaction between humans and systems in data processing. From the perspective of machinery involvement, automation levels are categorized into three stages, ranging from Smart to Semi-Autonomous, and ultimately to Autonomous. From the perspective of interaction between crew members and the system, four levels are identified, ranging from Manual to Smart, Semi-Autonomous, and Fully Autonomous [4]. Meanwhile, Lloyd's Register has outlined six levels of autonomy for MASS [5].

Such classifications are important in determining technical standards, legal obligations and the level of supervision required by national and international law. IMO has further recognized that the ships may operate at different levels of autonomy throughout a single voyage, which adds complexity to the creation of an appropriate legal framework and calls for considerable flexibility.

Although classification systems may vary in how many autonomy levels they identify, they all share the understanding that autonomy in MASS is not fixed but lies on a spectrum. A ship can be configured to function at various levels of autonomy depending on its operational circumstances, navigational area or particular mission requirements.

With the purposes of this research, the authors apply the IMO's four-tier classification system to maintain consistency and enable comparison with existing legal regimes. Accordingly, authors propose the following general definition: "A Maritime Autonomous Surface Ship refers to a civil or commercial ship intended to operate on the sea surface with varying levels of autonomy, which may function without the physical presence or direct control of crew. This is a new concept of ships and will continue to be improved in the future in parallel with the development of technology and the process of building a legal framework at both national and international levels on MASS.

2.2. Legal issues relating to maritime autonomous surface ships

IMO is taking a central role in coordinating and developing the international legal framework for MASS through the Regulatory Scoping Exercise (RSE), which began in 2017 and will complete its first phase in 2021 [6]. Preliminary results indicate that most existing conventions can be applied to MASS with specific amendments or guidance, particularly in terms of staffing, supervision and responsibility [7]. As a next step, IMO is promoting the drafting of the MASS Code – the International Code for Autonomous Ships, with a plan to adopt it by 1 July 2030 and expected to enter into force on 1 January 2032 [8].

The MASS Code, developed by the IMO, is built on a goal-oriented approach, aiming to create a flexible yet unified legal framework for the operation of autonomous vessels. The code comprises three main, mutually supportive parts. Part 1 defines the scope of application, objectives, concepts, and unifies technical and operational requirements. Part 2 outlines core principles and functions, including approval processes, management, warning systems, connectivity requirements, and the role of humans in a highly automated environment. Part 3 establishes functional requirements for each vessel system, from navigation and remote operation to firefighting and search and rescue.

These provisions in the MASS Code are all aimed at ensuring maritime safety, security, and efficiency, while also complementing important existing conventions such as MARPOL 73/78, UNCLOS 82, SOLAS 74, STCW 78/95-2010 and MLC 2006, particularly in regulating different levels of automation.

Meanwhile, countries such as the UK, Norway or Singapore are applying the regulatory sandbox and conditional exemption mechanism, both promoting technology testing and contributing practical data to the process of building an international legal framework for MASS. This mechanism is a new model, allowing subjects to test new technologies or operating models in a controlled and limited legal environment. This mechanism helps policymakers assess the practical impact of new technologies on the current legal system, thereby making appropriate adjustments without hindering technological development.

MASS is considered to have the potential to make a huge contribution to the maritime sector, but MASS also poses unprecedented legal and technical challenges. MASS is not simply a new means of transport but is also changing the nature of the current maritime industry. The emergence of MASS has raised many fundamental questions about the legal status of "ships", "crew", "operator", "captain", as well as legal responsibility in situations of collision, damage, pollution or maritime rescue. Notably, the absence of crew from ship operations challenges long-established assumptions within major maritime instruments, such as MARPOL 73/78, UNCLOS 82, SOLAS 74, STCW 78/95-2010 and MLC 2006.

Firstly, as required by the United Nations Convention on the Law of the Sea (UNCLOS 1982) [9], a State must ensure that ships flying its flag comply with safety rules and minimum safe manning standards (Article 94.3). However, this article does not clearly indicate whether personel are required to be physically on board, creating uncertainty about its interpretation in relation to MASS. Additionally, when no individuals are present on the ship port state control authorities may encounter difficulties in carrying out inspections or detaining ships when violations occur [10]. In addition, recent studies have also pointed out other aspects that MASS can impact the current regulations of UNCLOS such as: the concept of MASS, smart device surveillance, clearly defining safe speed for MASS, safe zone for MASS, identification signs for MASS (lights and displays on RADAR, ECDIS devices…) and amendments to regulations on sound signals [1].

The Convention on the International Regulations for Preventing Collisions at Sea (COLREG 72) [11] requires ships to maintain a proper lookout "by sight and hearing as well as by all available means." Replacing human lookouts with sensors and cameras on MASS presents one of the most significant challenges, and debates continue as to whether artificial intelligence can consistently meet the seamanship standard of competence in all situations [12].

In terms of training, education, certification and watchkeeping for seafarers as required by STCW 78/95-2010 [13], there are still views on whether the current STCW regulations are appropriate for remote control personnel, whether remote control personnel are required to be at the same level as officers or masters or whether they must maintain continuous watchkeeping as required by STCW [12]. The IMO is currently examining these issues to develop appropriate MASS-specific guidance.

The International Convention for the Safety of Life at Sea (SOLAS 74)) [14] requires "a sufficient number of competent seafarers to operate the ship safely" (Regulation 14). However, SOLAS 74 provides for the possibility of exemptions or equivalent arrangements, which could offer legal flexibility for the operation of MASS where approved by the flag State (Article 3.2).

The Maritime Labour Convention (MLC 2006) currently only applies to seafarers working on board ships. Therefore, if MASS is at levels 1 and 2, the convention still applies, however, if MASS is at levels 3 and 4, the scope and application of the convention will need to be reviewed and amended. If remote operators are classified as land-based workers, they will not be covered by the MLC provisions. Thereby, leading to a gap in labour rights for personnel managing MASS from shore-based control centres. Addressing this matter will require coordinated efforts between the IMO and the ILO to revise the concept of a "seafarer".

The International Convention for the Prevention of Pollution from Ships (MARPOL 73/78) establishes the obligations of seafarers to take pollution prevention measures during ship operations. In the case of the absence of seafarers, uncertainty arises about the relevance of some MARPOL provisions to MASS [15]. For instance, the Annex IV effluent certificate requirement may not apply to ships operating at Levels 3 and 4. Likewise, Annex V requirements such as: garbage records, garbage management plans and compliance with discharge guidelines – may need to be reviewed and revised.

Besides, The development of MASS represents one of the most significant technological transformations in modern maritime transport. While autonomy promises to enhance efficiency, safety, and reduce environmental impact [16], it also raises questions about liability for maritime accidents. Current liability regimes are developed based on assumptions about human decision-making, onboard crew, and direct navigation control. Therefore, researchers are increasingly questioning whether traditional maritime liability frameworks can adequately address accidents involving fully autonomous or semi-autonomous MASS vessels.

In the context of MASS, navigation decisions can be made by algorithms, artificial intelligence systems, or remote control centers, complicating the attribution of negligence [17], [18].

Some researchers argue that current conventions, including the COLREG 72, assume human judgment and situational awareness, making fault analysis difficult when decision-making is automated [19]. As autonomy increases, the causal chain between behavior and damage becomes less transparent, especially when self-learning systems adjust behavior after deployment. Therefore, the literature generally agrees that while current regimes may still be formally applicable, they are conceptually limited and operationally ineffective in addressing MASS-related accidents.

Despite these challenges, most studies conclude that legal liability is likely to remain primarily directed toward the shipowner or operator, at least in the short to medium term. This reflects the enduring structure of maritime law, which traditionally centers responsibility on the shipowner as the party exercising commercial control and benefiting from the voyage [18].

In cases where accidents occur due to software failures, sensor malfunctions, or algorithmic decisions beyond the owner's control, relying solely on the owner's responsibility risks misallocating liability and undermining the incentive for technological safety improvements [20]. This issue has fueled growing interest among researchers in models of liability allocation that go beyond the owner-centric framework.

One of the fastest-growing research directions concerns product and software liability in MASS accidents. Studies highlight that MASS relies on complex systems encompassing hardware, software, sensors, machine learning models, and input data, any of which can contribute to an accident [21].

Kim and Park also point out that defects arise from software updates or adaptive algorithms rather than static manufacturing errors. Scholars note unresolved issues related to defect standards, the burden of proof, and the identification of legally relevant defects in self-learning systems [21]. While product liability offers a potential avenue for redistributing responsibility to technology vendors, its integration into maritime accident cases remains theoretically uncertain.

In the book "Artificial Intelligence and Autonomous Maritime Transport: Developing an International Legal Framework," editors Baris Soyer and Andrew Tettenborn have compiled a comprehensive analysis of the legal challenges posed by MASS. The overarching theme of the book is liability, risk allocation, and insurance [22].

Liability issues are structurally emphasized in Part II of the book, which is almost entirely devoted to private law and liability issues. The focus is on Chapters 5 through 7, each examining a different aspect of liability and risk within the context of MASS. Chapter 5 emphasizes the growing importance of cyber risks and their potential to trigger liability when autonomous systems malfunction. The question that arises and needs to be answered through practice is whether existing models of liability, which have long been rooted in human error and navigational errors, are sufficient for a world where network-dependent autonomous operations are the norm [22]. Chapter 6 provides a detailed analysis of how traditional product liability doctrines can or cannot apply to autonomous vessels. It explains that while hardware or software failures may lead to product liability claims under domestic law, such an approach would not be entirely suitable for established maritime liability regimes, which typically focus on navigational negligence and operational risk. The chapter also highlights the difficulties in determining fault, duty of care, and cause when advanced artificial intelligence systems are involved [22].

In addition to these points, Chapter 7 assesses how marine insurers are likely to respond to the new risks associated with MASS. This chapter highlights that liability uncertainty - particularly when it overlaps with cyber risks and product defects - can affect the availability and terms of insurance. If insurers cannot reliably assess the extent of liability risk within existing legal frameworks, insurance capacity may be narrowed or auto-risks excluded, which would hinder the commercial viability of MASS [22].

The focus on liability and risk in Part II reflects the broader concern in the book that international law has not yet caught up with the reality of auto-risks. Part III, particularly Chapter 8, synthesizes the arguments presented in the preceding chapters and reiterates that gaps in legal responsibility are a difficult issue for MASS. The chapter's authors argue that existing instruments, such as SOLAS 74 and related conventions, are formulated based on the assumption of human presence and control, and therefore do not readily address situations where automatic decision-making replaces human roles [22]. The need for comprehensive international reform is emphasized as essential not only for safety and environmental protection but also to ensure a clear allocation of legal responsibility. Part I of the book lays a crucial foundation for these discussions by identifying the legal assumptions embedded in current maritime law. For example, Chapter 3 examines how core legal concepts such as negligent navigation, salvage, and limitation of liability have historically depended on the roles of the captain and crew. This chapter helps explain why issues of liability become so complex in the context of MASS [22].

The issue of marine insurance, particularly civil liability (P&I) insurance, is closely related to liability allocation. Research consistently points to uncertainty regarding whether existing insurance products adequately cover risks associated with automated operations, including network failures, software failures, and system integration errors [18].

Researchers emphasize that unclear liability allocation undermines insurability, as insurers rely on predictable risk profiles. This creates a legal vacuum where legal uncertainty slows down technology adoption.

To address these difficulties, an increasing number of researchers advocate for risk-based liability approaches or stricter liability for certain types of MASS-related accidents, particularly collisions. Authors supporting this argument argue that such models better reflect the inherent risks of autonomous navigation and simplify compensation by reducing the burden of proof for victims [23].

Although the number of research papers is increasing, some systematic gaps remain apparent. First, research has primarily focused on substantive liability rules, while procedural aspects-such as the burden of proof, access to algorithmic evidence, and standards of evidence-remain largely unexplored. Second, most studies are theoretical, reflecting a lack of judicial practice related to fully autonomous vessels (which is understandable given that this is the early stage of MASS testing, and therefore not many practical issues have arisen). Finally, aspects of public law, including the liability of the state registering the ship, environmental liability beyond oil pollution, etc., have received only limited attention to date.

Besides the issues already mentioned above, such as: legal status and applicability of existing maritime law; liability and attribution of responsibility; evidence, causation, and burden of proof; cybersecurity and autonomous risk; insurance and commercial viability, MASS also poses certain challenges to the global maritime industry. One of the most significant concerns is compliance with COLREG 72, maritime safety, and human-machine interaction. Research indicates that concepts such as "good seamanship" and the application of collision avoidance rules are difficult to translate into algorithmic logic [24]. Furthermore, the interaction between MASS and traditional vessels with crews on board further complicates this issue, especially on high-traffic shipping lanes.

Studies on human-machine interaction have found that MASS will operate for extended periods in a hybrid mode, involving remote operators and decision support systems rather than being fully automated [25]. However, the legal status, training standards, and liability of remote operators remain understudied, particularly in relation to existing conventions such as the STCW [26]. This represents a critical area where legal scholarship lags behind technological advancements.

3. LEGAL AND POLICY FRAMEWORKS OF SELECTED COUNTRIES IN THE REGION ON MARITIME AUTONOMOUS SURFACE SHIPS

3.1. Singapore's strategic policy on maritime autonomous surface ships

As a major global port state, Singapore is approaching the development of MASS with an emphasis on integrating such technologies into its smart port infrastructure and logistics network, while taking on the role of "enabler" through flexible mechanisms that foster innovation. Up to now, Singapore has not issued any specific legal guidelines for MASS. Instead, Singapore has chosen to focus on implementing MASS according to the sandbox model.

A Sandbox is a special testing area that allows companies to test MASS ships when there are no clear legal regulations. In other words, within the space and scope of the sandbox, even if MASS does not fully comply with current legal regulations, it is still allowed to operate as a normal ship. Currently, sandboxes are often deployed in two forms: Physical Sandbox operated in the real world, and Digital Sandbox [27] operated in laboratories with virtual reality technology. Accordingly, digital sandboxes are developed to support the operation of MASS in physical sandboxes, especially in the context of aiming for level 4 autonomy according to IMO classification. However, the Singapore government has not yet developed this type of virtual sandbox but mainly focuses on developing the physical sandbox model.

Sandboxes help identify and address bottlenecks in integrating MASS regulations into the regulatory framework. In this environment, entities are temporarily exempted from certain regulatory requirements, allowing them to test new technologies without fully complying with current regulations, as long as they ensure safety. For example, MASS may be exempt from design requirements, technical standards, human resources or inspections like conventional vessels. This model allows the regulatory agency to observe actual operations, collect data on safety, infrastructure and related factors to identify legal gaps and develop appropriate regulations. The sandbox testing data in Singapore is used to perfect future MASS legislation.

In addition to proactively conducting experiments to collect data, Singapore is also actively participating in MASS research internationally. In 2020, the Maritime & Port Authority of Singapore (MPA) initiated the establishment of MASSPorts, which includes 8 countries (Singapore, China, Denmark, Finland, Japan, the Netherlands, Norway, and South Korea). MASSPorts is essentially a legal sandbox located at Tuas Port (Singapore), with an international expansion element by allowing foreign organizations and businesses to access Singapore's testing infrastructure and sandbox model. For example, NYK Line (Japan) has collaborated with MPA and other organizations, research institutes to test autonomous ships in the Tuas Port area under Singapore's management to verify the interoperability between MASS and port operations systems [28].

In addition, MASSPorts also focuses on developing common guidelines for MASS testing in ports, including unifying terminology, standardizing signaling methods, and exchanging data between autonomous vessels and different port systems [29]. This common network is also conducting inter-port trials to verify system interoperability and propose international standards for MASS. Participating in MASSPorts promises to help countries like Vietnam take the lead in advanced technologies and build a legal framework to regulate MASS in accordance with international standards.

Prioritizing practical testing before issuing hard regulations allows Singapore to test new technology even when there is no clear regulation. New technology still has the opportunity to develop without the difficulty of waiting for the issuance of laws or official guidelines. This is a very proactive but also extremely cautious approach when following the IMO's roadmap for issuing a mandatory Code for MASS expected in 2030 (after an international testing phase from 2026). This will contribute to shortening the time to put the technology into practice and saving budgets on drafting legal documents and future amendment costs (in case Singapore's regulations conflict with the MASS Code).

3.2. Legal and policy framework of China for maritime autonomous surface ships

According to the 14th Five-Year Plan (2021–2025), the Chinese government approved the National Marine Economic Development Master Plan 2022 [30]. The plan outlined strategic directions for the development of smart and unmanned ships, established pilot areas, made breakthroughs in key technologies, expanded applications, focused on autonomous navigation technology, integrated sensors, remote control systems, artificial intelligence, the Internet of Things, and big data.

Accordingly, localities such as Liaoning, Guangzhou, and Guangdong were tasked with promoting the deployment and design of unmanned ships that comply with low-emission standards. Previously, in 2019, the Ministry of Transport, together with six other ministries, issued the Guiding Opinions on the Development of Smart Shipping [31], which outlined the roadmap: by 2020, complete the overall design; by 2025, make a breakthrough in automation technology; by 2035, master core technologies; and by 2050, form a high-quality intelligent maritime transport system. The main tasks include overall design, technological innovation, ensuring safety, strengthening the legal framework and training the maritime workforce.

In 2018, the Action Plan for the Development of Smart Ships (2019–2021) was issued [32], which stated the goal within three years to complete the establishment of preliminary standards, achieve achievements in technologies such as maritime situational awareness, autonomous docking, develop key equipment for autonomous ships, deploy pilot projects on remote control and autonomous operation, test smart platform applications, build virtual reality testing and verification capabilities. In parallel, the Action Plan for Promoting Smart Transformation in Ship Assembly and Construction (2019–2021) set out directions for smart manufacturing, 3D digital design, smart shipyards, and digital services.

On standardization, the Ministry of Industry and Information Technology issued the Guidelines for the Establishment of the Smart Ship Standards System (2019, revised in 2020) [33], dividing objectives into the 2020–2021 and 2022–2025 phases, comprising seven groups of standards ranging from general fundamentals, key technologies, and design, to systems and equipment, testing and verification, shore-based services, and operational management. The China Maritime Safety Administration (MSA) issued the Provisional Rules on the Technical Testing and Inspection of Autonomous Ships [34]. The 2023 Rules define the scope of application for vessels 20 meters or longer (Article 1.2.1), with the aim of guiding technical testing and ensuring maritime safety. According to Articles 3.1.3–3.1.6, autonomous vessels must possess autonomous operation capabilities, environmental sensors, an automated control system, comply with COLREG 72, and allow for manual intervention in emergencies. For remotely controlled vessels, requirements include stable connectivity, real-time data transmission, and equivalent navigation capabilities.

Article 2.2 stipulates that shipowners must develop a testing and risk assessment plan in accordance with IMO standards, including plans for responding to collisions, technical failures, and cyberattacks. Regarding data storage, Articles 3.10.3 and 4.4 require a minimum storage period of 30 days on board the vessel and over 6 months at the control station. The control system must be able to switch flexibly between three modes: automatic, manual, and remote (Article 3.1.5).

Regarding monitoring and warning, Article 3.7.1 requires the placement of a human-machine interface in the bridge of the autonomous vessel, providing information on control status, operating mode, route, hydrographic and meteorological conditions, surrounding environment, and system status. According to Article 3.3, the vessel must be equipped with a full range of sensors such as AIS, radar, GPS, 360° cameras, ensuring integration, redundancy, and data logging.

To minimize cybersecurity risks, Articles 3.8.1–3.8.2 require the design and application of protection measures in accordance with IMO MSC.428(98). In addition, the

2023 Rules add provisions for remote control stations (Chapter 4), requiring compliance with monitoring standards under Section 3.7.1 and the provision of backup control stations capable of immediate replacement in emergency situations (Sections 4.3.3–4.3.4).

MSA also issued the Technical Guidelines for Smart Ship Monitoring Systems 1.0. These guidelines establish technical standards for smart ship monitoring systems, specifically applicable to oil tankers, gas carriers, liquid chemical tankers, and inland passenger ships; other ship types may refer to them (Article 1.3). The system must utilize AI technology, high-resolution cameras (1080p), sensors, and edge processing equipment to detect anomalies, provide warnings, and handle incidents in real time without human intervention. Simultaneously, the system must integrate sensor data, connect to an onshore monitoring platform, and comply with cybersecurity standards GB/T 22239 and 25070 (Article 1.2).

Article 1.2 also lists the relevant technical standards that smart vessels must meet, including: GB/T 28181 on transmission and control of information in video surveillance; GB/T 20145 on optical biosafety; GB 17859 on classification of information system protection levels; and GB/T 3836 on flammable and explosive environments. For unmanned vessels, the entire monitoring, alerting, and data transmission process is automated, ensuring safety and continuous monitoring (Article 4.4).

In terms of classification and regulations, the China Classification Society (CCS) issued the Smart Ship Code 2015, which was subsequently revised in 2020 and 2024 [35]. The regulations classified intelligent ships into six functional categories, including provisions on remote control and automatic navigation, and included a number of specialized inspection standards. In 2025, the Regulations were revised, increasing the number of significant additions from 7 to 9 compared to the 2024 version. These additions include: principles for approving intelligent systems; revised certification requirements; structural monitoring and decision support function symbols; monitoring requirements for methanol/ammonia-based propulsion systems; principles for calculating energy efficiency for hybrid propulsion systems; risk analysis of automated liquid cargo handling systems; technical requirements for remote control stations; requirements for displaying parameters onboard vessels using electric propulsion and water jet propulsion systems; and requirements for situational awareness, autonomous decision-making, and anchorage equipment control.

In addition, the 2025 Regulations add requirements for intelligent arrangement (Gx) functionality, equipment condition management, and energy management. Overall, the amendments expand the standardization of smart vessels, integrate alternative fuels, automate docking and mooring, and enhance the requirements for interactive human-device interfaces.

At the same time, CCS issued the Guidelines for Inspection of Unmanned Surface Vessels in 2018, which were subsequently updated in 2024 [36].

The guidelines apply to unmanned vessels longer than 5 m but less than 20 m; vessels outside this range may refer to (Article 1.1.1). The guidelines specify requirements for classification testing, objectives and functional requirements, communication and control systems, hull, machinery, electrical systems, navigation equipment, signals, and additional symbols for each operating mode. The first revision (2018) added classification symbols, additional symbols, and testing requirements.

By 2024, the guidelines were further revised with the following main contents: detailed classification of three control modes (remotely controlled vessels, partially autonomous vessels, fully autonomous vessels); and the addition of regulations on inspection and approval related to the submission and verification of drawings, product acceptance, and out-of-test zone inspection. The technical requirements have been supplemented to include computer systems, network security, electromagnetic compatibility, data storage, autonomous operating conditions, remote control station design and layout, and alternative solutions, while also strengthening requirements for sensor systems, equipment configuration, and sensor installation.

CCS also issued the 2018 Automated Cargo Ship Guidelines [37], which builds on MAPOL 73/78, SOLAS 74 and COLREG 72. The Guidelines establish technical requirements applicable to MASS with automation levels 3 and 4. Finally, the 2020 Cyber System Requirements and Security Assessment Guidelines [38] establish comprehensive technical standards for cybersecurity for unmanned vessels, encompassing four main areas: functional requirements, system design, cybersecurity, and safety assessment. The network system must support real-time data transmission, integrate AI for autonomous navigation, and enable secure remote control. Network design requires a layered architecture, high-level encryption protocols, and hardware suitable for the marine environment; it must also implement end-to-end data protection, two-way authentication, and cyberattack response mechanisms. The system must undergo risk assessment and testing according to international standards for certification and operation.

According to Chapter 5, the ship's network system must undergo initial inspection, annual inspection (Article 5.3.1), and unscheduled inspection (Article 5.3.2). The guidance also includes six annexes relating to network risk assessment (Appendix 1), preliminary cybersecurity assessment (Appendix 2), equipment assessment (Appendix 3), network system assessment (Appendix 4), onboard network assessment (Appendix 5), and firewall recommendations (Appendix 6).

Under the Action Plan for the Development of Smart Ships (2019–2021), China completed the construction of 37.86 million dwt ships (47.3% of the global total), received new orders totaling 45.52 million dwt (55.2% of the global total), and has 105.57 million dwt remaining (49% of the global total) [39]. In addition, China successfully developed and built its first smart bulk carrier. The ship is equipped with intelligent systems such as automatic monitoring, energy management, equipment maintenance, and analysis of the status of key components like engines and propeller shafts. This vessel also received certifications from Lloyd's Register, a leading global ship classification organization, for “Cybersafe”, “Cyber-perform”, and “Cyber-maintain” as well as “intelligent ship” certification from the China Register of Shipping (CCS) [40]. In addition, ships such as the giant oil tanker New Journey in 2019 [41], the Yangtze River Three Gorges, a fully electric cruise ship [42], and the two largest fully electric container ships in the world, COSCO Greenwater 01 and 02 [43], are being developed and built by shipyards such as Dalian Shipbuilding Industries (DSIC) and Guangzhou Shipyard International (GSI). Hudong-Zhonghua Shipbuilding,…In particular, China has also strongly developed green and smart shipbuilding factories in a closed industrial chain (RD – shipbuilding – operation). These shipyards are all located in Hubei province along the Yangtze River to take advantage of inland waterway transport and the network of river ports [44]. These shipyards are fully equipped with modern technologies such as smart workshops utilizing 5G and IoT, robotic welding systems, big data analytics, and meeting green standards…helping the country’s shipbuilding technology increase threefold compared to previous levels. Following the success of the Under the Action Plan for the Development of Smart Ships (2019–2021), at the end of 2023, the Ministry of Industry and Information Technology (MIIT) and several other agencies officially issued the Action Plan for Green Development in the Shipbuilding Industry (2024–2030) [45]. The plan aims to transform the shipbuilding industry towards sustainable, environmentally friendly development, adopting green technologies and high industrialization. By 2025, China will have established a basic system for “green” development in shipbuilding and expects to become a leading nation in this field by 2030.

3.3. Korean strategic policy on maritime autonomous surface ships

In contrast to China, South Korea did not develop legal regulations for MASS beforehand, but instead chose a method of simulation - coastal testing - sea trials with small vessels - and commercial vessel testing. Based on real-world experiments, South Korea then developed technical standards and regulations related to MASS. Starting in 2019, the Ministry of Oceans and Fisheries (MOF) and the Ministry of Trade, Industry and Energy (MOTIE) announced their joint autonomous vessel project, named the Korean Autonomous Surface Vessel (KASS), running from 2020 to 2025 [46]. This project aims to develop core autonomous vessel technology and lay the groundwork for commercialization.

KASS’s current phase focuses on key technological and operational pillars such as:

1. Development of autonomous navigation systems, algorithm development, route planning, route tracking, automatic docking and departure [47].

2. Automation of propulsion and main engine systems, performance monitoring, fault diagnosis and prediction, failure prevention decision support, integration of virtual reality technology for remote technical support [48].

3. KASS designates the Autonomous Ship Verification and Evaluation Research Center (ASVERC) of the Korea Research Institute of Ships and Ocean Engineering (KRISO) as the main testing and approval center in Korea. KRISO built a simulation area, a shore-based engineering control room, servers, and also constructed a sea-based test area and a 26.5-meter test vessel [49]. ASVERC undertakes all testing, evaluation, and verification activities for KASS’s developed autonomous technology: from simulation and shore trials to sea trials. ASVERC collects operational data from the vessel, tests the automated navigation system and engine automation, conducts safety tests, and verifies the system to serve as the basis for certification [47].

4. Integrating hardware and software for operation, data exchange, shore-based control mechanisms, and coordination between ships (MASS with conventional vessels and between MASS).

5. ASVERC’s role is to provide empirical data to support the shipbuilding industry, prepare test data for participation in the development of technical standards, certification procedures, and propose a national legal framework for MASS.

In summary, the first five-year phase of Korea's MASS development plan, implemented through the KASS project, achieved the following results:

First, a series of trials was established, ranging from simulation – shore trials – trials with small vessels – sea trials – trials with commercial vessels. For example, in 2023, Samsung Heavy Industries (SHI) equipped a 15,000 TEU container ship with the Samsung Autonomous Ship SAS navigation system and SVESSEL solution for testing on a 1,500 km voyage from Geoje (South Korea) to Kaohsiung (Taiwan) [50]. During the voyage, the system used integrated RADAR, AIS, cameras, and sensors to detect over 9,000 obstacles and interact with approximately 90 vessels, making collision avoidance decisions that matched human decisions more than 90% of the time. The test also included intelligent functions such as monitoring, condition-based maintenance, electronic logs, and fuel efficiency optimization [51]. In 2024, the vessel named POS Singapore, a 1,800 TEU container ship equipped with an automated navigation system, departed from Busan port to begin a year-long sea trial from South Korea to Southeast Asian waters. The trial focused on evaluating three main functions: intelligent navigation, engine automation, and cybersecurity. The project is part of the Korea Autonomous Surface Ship (KASS) program, with the expectation that the trial data will contribute to the development of international standards for autonomous vessels at the IMO [52].

Secondly, KASS is not only a technology project, but also a collaborative model involving the State, research institutes, industry, and seaports to create a complete MASS value chain capable of competing internationally and setting global standards [49]. KASS divides tasks and coordinates actions among MOF, MOTIE, research institutes (KRISO), shipbuilding corporations, and ports. MOF plays a core role in KASS policy; MOTIE focuses on R&D technology and industrial production development; KRISO is considered the technological heart of KASS, acting as the central research unit, developing core MASS technologies and coordinating MASS testing; shipbuilding corporations such as

Table 1. Roles of stakeholders in the KASS project.

Subjects	Roles	Main Responsibilities
MOF	Policy – legal	Legal framework for MASS, testing, and safety standards.
MOTIE	Technology, Research and Development	Core technology, business support, commercialization.
KRISO	Technology Center	AI, sensors, systems, testing, standards.
Samsung/Hyundai/ Daewoo	Shipbuilding, technology integration	Design, shipbuilding, and installation of autonomous systems on commercial ships.
Ports	Operating infrastructure	Smart port, VTS, positioning, international testing.

Samsung Heavy Industries (SHI), Hyundai Heavy Industries (HHI), and Daewoo Shipbuilding & Marine Engineering (DSME) play a core role in industrial engineering deployment and integration of autonomous systems onto ships; and port systems undertake port automation, connectivity with MASS, synchronization with VTS (Vessel Traffic Service), providing precise positioning infrastructure, and cooperation on international test routes. The roles of each party are shown in the Table 1.

Finally, regulations for MASS were enacted. On January 2, 2024, the Law on the Promotion of the Development and Commercialization of Autonomous Vessels (Law No. 19909) was officially promulgated [53]. The law is enacted to promote the development of core technologies and equipment for autonomous vessels, build a foundation for the safe operation of autonomous vessels, and establish a maritime logistics system to support the commercialization of autonomous vessels (Article 1). The law will take effect one year after its promulgation.

Article 2, paragraph 1, section 1 of this Law defines “autonomous vessel” as a vessel capable of self-operation using an automated system without any human intervention, such as a crew member or remote operator. The Act stipulates that the Ministry of Oceans and Fisheries (MOF) and the Ministry of Trade, Industry and Energy (MOTIE) must coordinate in developing a five-year master plan for the development and commercialization of autonomous vessels (Article 4).

Based on this, MOTIE is responsible for developing and implementing a plan for the development of autonomous vessel technology (Article 5), while MOF is responsible for developing and implementing annual plans to promote the application of autonomous vessels and the formation of a suitable maritime logistics system (Article 6). These two ministries will also establish a committee of experts and representatives from government agencies to review, advise on, and decide on important policies and issues related to autonomous vessels (Article 8).

According to the law, the Ministry of Maritime Affairs (MOF) has the authority to determine operating areas for autonomous vessels (Article 9, paragraph 1). These are areas designed to ensure that autonomous vessels can operate safely and receive necessary support (Article 2, paragraph 1, section 5). The MOF, together with the local authorities where these areas are located, will implement measures to ensure the safe operation of autonomous vessels (Article 9, paragraphs 2 and 3).

In addition, the MOF is tasked with organizing projects to build maritime logistics systems to serve autonomous vessels, including upgrading maritime traffic information services, modernizing information and communication infrastructure, and automating port facilities (Article 12).

The MOF will also set the necessary conditions for the operation and verification of autonomous vessels, and conduct safety assessments of related vehicles and equipment (Article 19). Organizations or individuals wishing to test or demonstrate autonomous vessels must purchase civil liability insurance and obtain an operating license from the MOF; when granting the license, the MOF may impose additional conditions to ensure safety during operation.

3.4. Japan’s national strategy and policy on maritime autonomous surface ships

Japan’s policies and strategies regarding MASS development are manifested at various levels and degrees. The first is clearly evident at the national level. Japan has emerged as one of the leading nations in the structured development of the MASS system, driven by a coordinated national policy framework under the Ministry of Land, Infrastructure, Transport and Tourism (MLIT). Instead of pursuing complete autonomy as an immediate goal, Japan has adopted a phased strategy focused on safety, integrating technological development, practical testing, and early legal and regulatory adjustments. This approach reflects both Japan's strong maritime tradition and its awareness of the legal and operational limitations imposed by existing international maritime law.

At the core of Japan’s MASS policy is a formal national roadmap aimed at implementing and commercializing MASS practices by around 2025. This roadmap prioritizes intermediate levels of autonomy, often referred to as MASS Stage II, where onboard crew members remain responsible for final navigation and operational decisions while benefiting from advanced automation and decision-support systems [54]. This roadmap is integrated into a national maritime innovation strategy, addressing the challenges facing the Japanese shipping industry, including crew shortages, an aging workforce, and increasing international competition. By focusing on supportive autonomy rather than immediate unmanned operation, Japan seeks to enhance operational efficiency while maintaining continuity with existing legal concepts such as captain authority and onboard responsibility.

Japan's MASS policy is guided by two closely related objectives: safe and efficient navigation while improving seafarer working conditions. MLIT has always viewed autonomy as a means to minimize human error, reduce fatigue, and support decision-making, rather than as a replacement for human capabilities [55]. This human-centered approach remains strongly consistent with current international regulations in documents such as SOLAS 74, COLREG 72, etc. Simultaneously, MASS development is defined as a competitive strategy. Improving ship efficiency and safety through automation is considered essential to maintaining the global position of Japan's shipping and shipbuilding industry. Therefore, the MASS policy is not a standalone technology experiment but part of a long-term industrial and maritime governance program [55].

A key feature of Japan's MASS framework is its strong emphasis on empirical validation through large-scale projects. Since 2018, MLIT has funded and coordinated programs focused on critical support technologies, including autonomous navigation, onshore remote control, and automated docking and mooring systems [56]. These projects are conducted in real-world operating environments, allowing regulators and developers to assess system performance under real-world conditions.

These practical projects help Japan achieve multiple objectives. Technically, they enable iterative improvement of autonomous systems. Institutionally, they provide evidence to support the development and enactment of regulatory frameworks. Normatively, they reinforce a safety culture from the design stage, ensuring that autonomous capabilities are introduced gradually and transparently. This trial-based model bridges the gap between research and commercial deployment, while enhancing the credibility of Japanese regulatory statements in international forums.

In February 2022, MLIT issued Safety Guidelines for MASS, marking a significant step toward regulatory consolidation. These guidelines outline fundamental safety principles covering ship design, system installation, operating procedures, and risk management [57]. While not legally binding, these guidelines act as a soft legal tool, providing authoritative guidance to stakeholders in the maritime industry while allowing flexibility in the initial stages of MASS deployment. Importantly, these guidelines address human-machine interaction and the allocation of responsibilities between onboard personnel and automated systems. This reflects the understanding that legal uncertainty often arises not from the technology itself but from an unclear accountability structure. By clarifying responsibilities at the design and operational levels, MLIT has laid the groundwork for a smoother integration of MASS into existing legal frameworks.

Japan's MASS roadmap clearly recognizes that technological development must go hand in hand with legal adaptation. At the national level, Japan identifies the current critical issue as ensuring the compatibility of MASS with existing maritime regulations while avoiding premature legal rigidity [54-57]. Internationally, Japan has played an active role in the IMO, contributing to discussions on the Scope Review of Regulations and the development of future MASS instruments, including the proposed MASS Code [58].

This two-pronged strategy-domestic preparation combined with proactive international engagement-has established Japan as a constructive norm-setting nation in global MASS governance. Instead of waiting for binding international rules to emerge, Japan has proactively implemented measures domestically and made significant contributions internationally.

Japan's national legal framework for MASS demonstrates a carefully balanced approach to innovation, safety, practicality, and legal continuity. Through a clear strategic plan, progressively increasing autonomy, extensive field trials, and the use of safety guidelines via soft law, Japan has established a coherent roadmap toward the commercialization of MASS Phase II. The emphasis on human-centered autonomy and early regulatory adjustments provides a practical model for other maritime nations transitioning to automated shipping, particularly within the framework of existing international maritime law.

At the next level, the development of MASS in Japan is characterized not only by state-led policy but also by extensive cooperation between the public and private sectors, including shipping companies, shipbuilders, technology providers, and non-governmental organizations. These collaborative initiatives play a crucial role in translating national policy objectives into practical operational capabilities. One of the most notable collaborative initiatives is the DFFAS project (Design for the Future of Fully Autonomous Vessels), which brings together around thirty stakeholders in the Japanese maritime sector, including major operators such as Nippon Yusen Kaisha (NYK Line) and the Monohakobi Technology Institute (MTI) research division, along with support from public organizations and funds. This project aims to establish the necessary technological and institutional foundations for the future deployment of fully autonomous vessels, while aligning with Japan's phased autonomy roadmap [59]. A key outcome of the DFFAS initiative is the establishment of the Fleet Operations Center (FOC) in Makuhari, Chiba [60]. The FOC functions as an onshore monitoring and support center, enabling remote monitoring of vessels, situational awareness, and emergency preventative intervention during autonomous vessel trials. This infrastructure is designed to support practical experiments in busy coastal waters and inland shipping lanes, reflecting Japan's emphasis on testing MASS under real-world maritime conditions [60]. The practical experiment phase of the project is clearly linked to Japan's other objective of achieving the practical deployment of MASS Phase II around 2025 [60].

Alongside short-term pilot projects, Japan has launched long-term research initiatives aimed at addressing the future of automated maritime transport with the initial goal of commercialization. The MEGURI2040 Fully Autonomous Vessel Program, led by the Nippon Foundation, sets a long-term vision to achieve fully autonomous vessels by 2040 [61]. This program integrates technological development, legal vision, and international cooperation, positioning Japan as a long-term leader in the field of automated maritime systems [61]. Within the framework of MEGURI2040, the Japan Society for Ship Technology Research (JSTRA) plays a central role in conducting safety and risk assessments for the MASS system [61]. This work focuses on validating the system's reliability, redundancy, and human-machine interaction, ensuring that technological innovation proceeds in parallel with safety and legal readiness. These assessments contribute empirical evidence to both domestic policymaking and Japan's participation in international legal discussions at the IMO [61].

Beyond in-depth research projects, Japanese shipping companies have begun integrating Maritime Digital Transformation (MAX) technology and automated navigation functionality into their commercially operating vessels, including bulk carriers and car carriers [62], [63]. These trials involve installing advanced sensor systems, AI-powered navigation tools, and data-driven operational support systems within existing fleet operations. Such commercial trials are crucial because they allow for large-scale testing of automated technologies in routine maritime operations, rather than just in individual test settings. This approach reflects Japan's pragmatic philosophy for MASS development, where high levels of automation are integrated into commercial practices to generate operational data, improve safety performance, and enhance competitiveness. As a result, MASS development in Japan does not function as a standalone technological experiment, but rather as an integral component of a long-term industrial and maritime governance strategy.

At the final level, Japan has actively participated in IMO activities concerning MASS, particularly in the Maritime Safety Committee (MSC) and other IMO subsidiary bodies [3]. During the IMO Regulatory Scope Review (RSE) (2018–2021), Japan consistently supported the view that existing conventions-most notably SOLAS 74, COLREG 72, and STCW 78/95-2010 - cannot fully address MASS operations without clear interpretation or systematic revision [3]. Accordingly, Japan, along with other leading maritime nations in the region such as South Korea and China, has advocated for a dedicated international legal instrument for MASS, rather than fragmented or unilateral national approaches [3]. Japan's contributions to the IMO are characterized by three core legal principles. Initially, Japan has promoted technological neutrality, aiming to avoid premature regulation of specific autonomous systems. Secondly, Japan has emphasized the principle of functional equivalence, acknowledging that remote operators and automated systems can be legitimate substitutes for onboard crews if equivalent safety outcomes are achieved. Finally, Japan advocates a step-by-step management approach, prioritizing non-mandatory tools as a transitional step before adopting binding regulations. These perspectives have directly influenced the IMO's decision to develop a non-mandatory MASS Code as a provisional framework, followed by the development of a mandatory MASS Code, now expected to be adopted around 2030 [3].

One of Japan's most concrete contributions to the region regarding MASS is its participation in the MASSPorts Initiative, a multilateral cooperation platform encompassing port and maritime authorities from Japan, Singapore, China, South Korea, and other countries in the Asia-Pacific region [64]. MASSPorts was established to address the operational and safety challenges posed by MASS at ports, which are key differences between MASS and conventional waterway traffic and onshore authorities [64].

In Southeast Asia, Japan cooperates with ASEAN on maritime governance primarily through the ASEAN-Japan Transport Partnership and the ASEAN Maritime Transport Working Group (MTWG) [65]. While the MTWG has not adopted any specific legal instruments related to MASS, it plays a crucial role in shaping the region's maritime safety innovation, digitalization and smart shipping, as well as its alignment with evolving IMO regulations. Japan's contributions to the MTWG discussions included sharing safety assessment methodologies applied in MASS trials, clarifying the IMO's MASS regulatory roadmap - including the sequence of implementing mandatory and non-mandatory instruments - and assisting ASEAN member states in understanding the legal and institutional implications of future MASS regulations. Through this participation, Japan helped translate the complex IMO processes into regulations that are easily accessible to regulatory bodies with varying levels of technical capacity [65].

4. LESSONS FOR VIETNAM AND OTHER COUNTRIES IN THE REGION

Up to now, the Vietnamese legal system has no legal regulations that directly or indirectly regulate MASS. While some countries have issued technical guidelines or are in the process of amending the law, in Vietnam, the current legal framework is still based on the traditional model, requiring the presence of crew members on board.

The 2015 Vietnam Maritime Code does not have any mention of the concepts of "MASS", "remote-controlled ships", or "unmanned vehicles". According to Clause 1, Article 3, "seagoing vessels" are defined as floating vehicles operating at sea for purposes such as transportation, scientific research or national defense. However, these concepts, together with provisions on "master" (Article 130) and "crew" (Article 147) are fundamentally constructed on the basis that personnel are physically and continuously present on board. Accordingly, MASS at autonomy levels 3 and 4 means that the ships with no crew physically on board or operated fully autonomously, which leads to significant legal gaps regarding registration, testing, insurance and liability in the event of incidents.

Moreover, key legislation of Vietnam, including the Law on Inland Waterway Traffic 2004 (amended 2014), the Vietnam Maritime Code 2015 (under review 2025), the Law on High Technology 2008 (under revision 2025) and the Law on Cyber Information Security 2018, does not incorporate rules compatible with the operational reality of unmanned transport systems. Consequently, this regulatory gap restricts technological advancement and delays the deployment of MASS in promising fields such as environmental monitoring, hydrographic surveying, short-sea shipping and unmanned maritime search and rescue. Therefore, studying the policies and strategies of exemplary countries will have significant theoretical and practical value for Vietnam in the present and future.

Currently, the Vietnamese Maritime Code is undergoing comprehensive revision to keep pace with the global maritime industry. Important documents from the Ministry of Construction [66] and the Vietnam Maritime and Waterway Administration [67] have mandated a thorough review of the Code's contents. Issues requiring clarification include the concepts of MASS and Sandbox, which are being proposed for inclusion in the Code by experts, researchers, state management agencies, and maritime transport companies.

In-depth research into the legal policies and MASS development strategies of various countries offers valuable experience for Vietnam, including:

Firstly, Singapore's flexible approach prioritizes digital sandboxes and controlled testing.

Singapore's experience shows that building a complete legal framework from the outset is not a mandatory requirement for developing countries in the MASS field. Instead, Singapore chose a flexible legal model, leveraging existing legal systems combined with a testing mechanism (sandbox) to control risks and simultaneously promote innovation.

Initially, the application of digital sandboxes was seen as an effective step, especially for countries with limited resources like Vietnam. Digital sandboxes allow for comprehensive testing of MASS functionalities in a simulated environment at low cost, without requiring large-scale infrastructure investment, and support the observation and evaluation of technology before field deployment. Besides Singapore, South Korea is also actively implementing a digital sandbox within the framework of the Korea Autonomous Surface Ship (KASS) project, demonstrating outstanding effectiveness in risk assessment and technology adaptation.

When resources permit, a field sandbox can be developed following the Singapore model to facilitate testing of MASS systems under real-world operating conditions. Singapore's experience also emphasizes the role of international cooperation, particularly through the MASSPorts initiative, which helps share testing facilities and reduce domestic investment costs-a practical solution for Vietnam.

Furthermore, Singapore implements a case-by-case MASS testing licensing mechanism with strict deadlines and conditions. This approach allows MASS to operate within a controlled legal framework while ensuring maximum maritime safety. Vietnam could adopt this licensing model in the initial phase, incorporating requirements for vessel tracking, monitoring equipment, emergency control centers, and operational area limitations.

Secondly, China prioritizes the completion of legal frameworks according to a roadmap and clearly defines inter-sectoral responsibilities.

China is one of the few countries to issue its own regulations on autonomous vessels at the local level and conduct large-scale field trials. However, this model is only suitable for countries with strong technological capabilities and governance systems. For Vietnam and most Southeast Asian countries, building a similar set of specialized regulations to China is not an optimal choice, as it requires significant resources and a complex inter-sectoral coordination mechanism.

In the context of the IMO finalizing the MASS Code and the expected adoption of a non-mandatory version in 2026, the appropriate solution for Vietnam is to maximize the use of the existing legal framework and implement a roadmap for adjustment during the 2024-2030 period. This includes three phases:

(1) Temporarily managing MASS based on existing legal regulations and issuing technical guidance on testing;

(2) Integrating the non-mandatory MASS Code after 2026 to standardize terminology, determine autonomy levels, and establish testing standards;

(3) Amending or supplementing the Maritime Code 2015 and subordinate legislation after 2030 when the mandatory MASS Code comes into effect.

Another important lesson from China is the need for inter-sectoral responsibilities. MASS management involves transportation, science and technology, industry and trade, and national security and defense, which can easily lead to overlaps if there is a lack of unified coordination. Therefore, Vietnam needs to quickly identify a focal agency responsible for overall coordination and establish a clear inter-sectoral coordination mechanism to ensure effective governance and policy consistency.

Thirdly, South Korea's clear testing roadmap and unified national program

South Korea adopts a cautious and systematic approach to MASS development. Instead of enacting legal regulations early, South Korea prioritizes empirical data, implementing a phased testing roadmap: simulation - onshore testing - testing on small coastal vessels - testing on commercial vessels - and finally building a legal framework. This approach ensures that all legal regulations are based on practical experience and are highly feasible. Vietnam can apply this roadmap to avoid the risk of enacting policies without sufficient empirical evidence.

Another highlight is the KASS program representing a model of organized and effective national-level implementation. Based on this experience, Vietnam needs to develop a national MASS program, clearly assigning responsibilities to the Ministry of Transport and the Ministry of Science and Technology, defining technological objectives, testing roadmap, participating agencies, budget, and outputs.

South Korea also established the ASVERC testing center, providing full capabilities for simulation, marine testing, safety analysis, and certification. This model suggests that Vietnam could consider building a similar center in Hai Phong or Vung Tau, while coordinating with domestic enterprises such as Hyundai Shipbuilding Vietnam Co., Ltd. (HVS), Vietnam Maritime Corporation (VIMC), Shipbuilding Industry Corporation (SBIC) to ensure testing capacity and technology development. Therefore, for Vietnam at the present stage, applying the approach of Singapore or South Korea would be more advantageous than that of China. After successful testing and sufficient resources are available, the Chinese approach should be applied to the finalization of the MASS legislation.

Fourthly, based on research into Japan's strategic and policies, the following experiences may be relevant to Vietnam: Prioritize Phase II of MASS (seafarer-assisted autonomous operation) rather than immediately deploying MASS, ensuring compatibility with existing maritime law and operational practices; Develop non-binding guidelines or administrative documents to manage the initial trials and deployments of MASS, while avoiding premature legal rigidity; View automation as a tool to support seafarer decision-making, improving safety and working conditions rather than replacing human responsibilities; Utilize the participation of the ASEAN Multi-Sector Working Group (MTWG) to access technical knowledge, understand IMO management roadmaps, and build institutional readiness without formal legal commitments; Monitor and harmonize domestic policies with non-binding IMO guidelines and the future MASS Code to ensure the international operational capability of Vietnamese-flagged vessels.

Simultaneously, similar to other countries such as South Korea or China, Vietnam needs to: Promote controlled MASS inspections in coastal waters and ports to collect empirical data to support the development of evidence-based regulations and ensure safety; Encourage cooperation among government agencies, shipping companies, ports, and technology providers to translate policy objectives into practical action.

Finally, Vietnam, as well as other countries in the region, needs to strengthen international cooperation and exchange experiences in the region and the world. In this aspect, Vietnam needs to be more proactive in participating in activities such as discussions or workshops in the region and the world, as well as those organized by IMO on MASS (typically the development and completion of the MASS Code). At the same time, when developing and completing domestic regulations, it is necessary to refer to the standards issued by the IMO.

5. CONCLUSION

This study has analyzed the legal and policy frameworks for MASS in Singapore, China, South Korea and Japan to draw lessons for Vietnam. The comparison shows that there is no single regulatory model for MASS; national approaches depend largely on technological capacity, governance structures, and development objectives.

Singapore's experience highlights the benefits of a flexible, sandbox-based approach that prioritizes testing and international cooperation over early legislation. This model supports innovation while managing risks and preparing for future regulation in line with the IMO's MASS Code roadmap. China, by contrast, has developed a comprehensive regulatory framework supported by strong industrial and technological capacity. While effective, this approach requires significant resources and is more suitable for the later stages of legal development in Vietnam. South Korea and Japan provides the most relevant reference for Vietnam. Through the KASS program of Korea or project of Japan, Korea and Japan adopted a clear, phased testing roadmap and enacted legal regulations only after sufficient empirical evidence had been gathered. This approach ensures that regulation is practical and technically feasible.

Based on these lessons, Vietnam should follow a gradual and flexible pathway. In the short term, MASS can be managed under existing laws, supplemented by technical guidance and controlled testing, including digital sandboxes. In the medium to long term, Vietnam should align its regulatory roadmap with the IMO's non-mandatory and mandatory MASS Code, while strengthening inter-sectoral coordination and designating a focal authority. Over time, establishing a national MASS program and testing infrastructure, drawing mainly on the Korean model, will support effective and internationally aligned governance of MASS.

REFERENCES

[1] V. D. Cuong and N. V. Phuong, "Autonomous surface vessels from a comparative law perspective: The cases of the United Kingdom and China, and implications for Vietnam," *Development & Law* (Pháp luật và Phát triển), 2025.

[2] V. T. Nguyen, T. L. Nguyen, and D. T. H. Nguyen, "A study on legal issues regarding maritime autonomous surface ships and their impact on the regulations of the Convention on the International Regulations for Preventing Collisions at Sea," *Journal of Marine Science and Technology*, vol. 77, no. 77, pp. 101–116, 2024.

[3] International Maritime Organization, "Autonomous shipping," 2021.

[4] American Bureau of Shipping, "Advisory on autonomous functionality," *Advisory*, 2020.

[5] I. Kurt and M. Aymelek, "Operational and economic advantages of autonomous ships and their perceived impacts on port operations," *Maritime Economics & Logistics*, vol. 24, no. 3, pp. 302–326, 2022.

[6] International Maritime Organization, "Autonomous ships: Regulatory scoping exercise completed," 2021.

[7] International Maritime Organization, "Outcome of the regulatory scoping exercise for the use of Maritime Autonomous Surface Ships (MASS) (MSC.1/Circ.1638)," 2021.

[8] International Maritime Organization, "Maritime safety committee – 108th session (2024)," 2024.

[9] United Nations, "United nations convention on the law of the sea (UNCLOS)," 1982.

[10] D. M. Coello, "Is UNCLOS ready for the era of seafaring autonomous vessels? " *Journal of Territorial and Maritime Studies*, vol. 10, no. 1, pp. 21–37, 2023.

[11] International Maritime Organization, "Convention on the international regulations for preventing collisions at sea (COLREG)," 1972.

[12] H. Ringbom, E. Røsæg, and T. Solvang (Eds.), *Autonomous Ships and the Law – 1st Edition*, Routledge, 2020.

[13] International Maritime Organization, "International convention on standards of training, certification and

watchkeeping for seafarers (STCW)," 1978.
[14] International Maritime Organization, "International convention for the safety of life at sea (SOLAS), Consolidated Edition," 1974.
[15] International Maritime Organization, "International convention for the prevention of pollution from ships (MARPOL) [As amended 1978]," 1973.
[16] R. García-Llave, F. H. Echeverry Andrade, and D. J. Coronil Huertas, "Autonomous ships and flag state: Challenges and opportunities in international maritime law," *Journal of Transportation Security*, vol. 18, no. 1, pp. 15, 2025.
[17] L. Carey, "Contractual and tortious maritime liability regimes and the introduction of autonomous vessels," NUS Law Working Paper No. 2023/012, Centre for Maritime Law, National University of Singapore, 2023.
[18] E. Szewczyk, "Tortious liability for collisions involving uncrewed and autonomous marine surface ships in English law and the resulting implications for protection and indemnity insurance cover," *Doctoral thesis*, Northumbria University, 2024.
[19] C. H. Chang et al., "COLREG and MASS: Analytical review to identify research trends and gaps in the development of autonomous collision avoidance," *Ocean Engineering*, vol. 302, pp. 117652, 2024.
[20] L. Chen, "Maritime rights, obligations, and liabilities of intelligent ships from the perspective of risk distribution," *Journal of International Maritime Safety, Environmental Affairs, and Shipping*, vol. 7, no. 4, pp. 2264566, 2023.
[21] J. Kim and S. Park, "Potential liability issues of AI-based embedded software in maritime autonomous surface ships," *Journal of Marine Science and Engineering*, vol. 10, no. 4, pp. 498, 2022.
[22] B. Soyer and A. Tettenborn, Eds., *Artificial Intelligence and Autonomous Shipping: Developing the International Legal Framework*, Hart Publishing, 2021.
[23] M. Mesiya Peter and M. Ma, "Tortious liability for autonomous marine vehicle collisions: A suggestive move from fault-based to strict liability," *Ocean & Coastal Management*, vol. 269, pp. 107781, 2025.
[24] S. Hasan, "Regulating maritime autonomous surface ships: Recent developments and challenges," *Ocean Yearb. Online*, vol. 39, no. 1, pp. 330–349, 2025.
[25] T. Porathe, J. Prison, and Y. Man, "Situation awareness in remote control centres for unmanned ships," *Proceedings of Human Factors in Ship Design & Operation*, pp. 93–101, 2014.
[26] M. A. Ramos et al., "Human-system concurrent task analysis for maritime autonomous surface ship operation and safety," *Reliability Engineering and System Safety*, vol. 195, pp. 106697, 2020.
[27] Lloyd's Register, "Maritime autonomous surface ships: Human element, design and operations (Version 6)," 2025.
[28] NYK Line, "NYK conducts world's first international demonstration test of a fully autonomous ship," 2025.
[29] Maritime and Port Authority of Singapore, "Flag, coastal and port authorities from eight countries come together to encourage development of maritime autonomous surface ships," 2020.
[30] State Council, "Reply of the state council on the 14th five-year plan for marine economy development," 2021.
[31] Ministry of Transport and six other ministries, "Guiding opinions on the development of smart shipping," 2019.
[32] Ministry of Industry and Information Technology, Ministry of Transport, and State Administration for Science, Technology and National Defense Industry, "Action plan for the development of intelligent ships (2019–2021)", 2019.
[33] Ministry of Industry and Information Technology, "Guidelines for the development of the smart ship standards system," 2019.
[34] China Maritime Safety Administration, "Provisional rules for the technical testing and inspection of autonomous ships," 2023.
[35] China Classification Society, "Smart ship code 2015," 2015.
[36] China Classification Society, "Guidelines for unmanned surface vessels inspection," 2018.
[37] China Classification Society, "Guidelines for autonomous cargo ships," 2018.
[38] China Classification Society, "Guidelines for ship network system requirements and safety assessment," 2020.
[39] State Council of the People's Republic of China, "China continues to lead in global shipbuilding market," 2023.
[40] L. Zhao, "World's first smart ship developed and built in China," *China Daily*, 2017.
[41] M. Schuler, "China delivers first 'smart' VLCC," *gCaptain*, 2019.
[42] J. Chi, "China constantly accelerates green, smart shipbuilding," *Global Times*, 2024.
[43] COSCO Shipping Holdings Co., Ltd., "World's largest electric container ship starts regular service," 2024.
[44] T. Chen, "Shipbuilding becomes greener, smarter in China," *Global Times*, 2024.
[45] State Council of the People's Republic of China, "China releases action plan to foster green development in shipbuilding industry," 2023.
[46] Korea Autonomous Surface Ship Project, "History,"2019.
[47] Korea Autonomous Surface Ship Project, "Development of autonomous navigation system with intelligent route planning function," 2020.
[48] Korea Autonomous Surface Ship Project, "Technology," 2020.
[49] Autonomous Ship Verification & Evaluation Research Center, "Autonomous ship testing, evaluation and verification research hub utilizing the world's only land and sea testbed," *Korea Research Institute of Ships & Ocean Engineering*, 2020.
[50] Maritime Activity Reports, Inc., "SHI tests autonomous navigation system on container ship," *MarineLink*, 2023.
[51] The Maritime Executive, "Containership sails 800 NM trip using Samsung's autonomous navigation," *The Maritime Executive*, 2023.
[52] D. H. Ko, "Korea's autonomous ship sails to Southeast Asia for test," *The Korea Times*, 2024.
[53] Ministry of Oceans and Fisheries, "Enactment of the enforcement decree of the act on the promotion of development and commercialization of autonomous ships," *Government of Japan*, 2025.
[54] Ministry of Land, Infrastructure, Transport and Tourism, "Formulation of safety guidelines toward the practical implementation of autonomous ships: Further promoting the development and commercial deployment of autonomous ships by operators," *Government of Japan*, 2022.
[55] Ministry of Land, Infrastructure, Transport and Tourism, "Maritime: Autonomous ship study group," *Government of Japan*, 2025.
[56] Ministry of Land, Infrastructure, Transport and Tourism, "Efforts toward the practical implementation of autonomous ships," *Government of Japan*, 2018.
[57] Ministry of Land, Infrastructure, Transport and Tourism, "Safety guidelines for maritime autonomous surface ships," *Government of Japan*, 2022.
[58] Ministry of Land, Infrastructure, Transport and Tourism, "Trends in international regulations related to maritime autonomous surface ships," *Government of Japan*, 2025.
[59] NYK Line, "Documentary of fully autonomous ship

project released," *NYK Line English News*, 2022.
[60] NYK Line, "Fleet operation center completed for crewless maritime autonomous surface ship project," *NYK Line English News*, 2021.
[61] The Nippon Foundation, "The Nippon foundation MEGURI2040 Fully autonomous ship program," 2020.
[62] Nippon Yusen Kabushiki Kaisha, "Automobile carrier equipped with marine DX equipment begins operations," *NYK Line*, 2025.
[63] Maritime Activity Reports, Inc., "Autonomous containership trialed in Japan," *MarineLink*, 2022.
[64] Maritime and Port Authority of Singapore, "Flag, coastal and port authorities from eight countries come together to encourage development of maritime autonomous surface ships," 2020.
[65] Vietnam Maritime and Waterway Administration, "Vietnam maritime administration chaired the 42nd ASEAN maritime transport working group meeting," 2022.
[66] Ministry of Construction, "No.3692/BXD-PC: On the detailed plan for drafting the Vietnamese maritime code," Hanoi, Vietnam, 2025.
[67] Vietnam Maritime and Waterway Administration, "No.154/QD-CHHDTVN: Decision on the restructuring of review, research, and policy/project dossier preparation teams for the Vietnamese Maritime and Inland Waterways Code," Hanoi, Vietnam, 2026.