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**REGULATORY CHALLENGES AND LIABILITY FRAMEWORK FOR
MARITIME AUTONOMOUS SURFACE SHIPS: A PROPOSAL FOR
REGULATIONS AND STATE ADAPTATION TO VESSEL AUTONOMY**

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DEDICATION

To God, for he never leaves me alone and grants me strength.

To my parents, Yuri and José, to whom I dedicate my entire career, for their sacrifices, dedication, love, support, and the values they instilled in me, which have guided me throughout my life and studies. I promise I will never take for granted what you have done for me.

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Abstract. The emergence of Maritime Autonomous Surface Ships (*MASS*) represents one of the most profound transformations in the maritime industry, challenging traditional notions of safety, liability, and regulatory oversight. This thesis argues that liability for harm caused by *MASS* should be primarily allocated through a *product liability framework*, assigning responsibility to manufacturers, integrators, programmers, and vendors of critical systems, while also establishing clear duties for shipowners and operators. It further develops a structured framework for the *liability of Remote-Control Centers (RCC)* and shore-based operators, setting out standards of care, attribution of operational fault, shared liability, and their interaction with limitation regimes and compulsory insurance. Through a comparative analysis of international conventions, Mexico's Maritime Navigation and Commerce Law, and emerging IMO studies on regulatory gaps, the research demonstrates that current obligations of seaworthiness, *safe manning*, and fault attribution are inadequate for uncrewed or remotely controlled ships. To close this gap, it proposes a *product liability-based model* supported by mandatory insurance regimes, in which manufacturers, programmers, and operators assume more clearly defined responsibilities. Beyond theoretical analysis, this thesis provides a *practical roadmap for States and the IMO to adapt legislation*, harmonize international standards, and anticipate ethical, contractual, and extra-contractual challenges of *MASS*. In this sense, it serves as a *legal guide for policymakers* to secure accountability, safety, and innovation in the era of autonomous navigation.

Key words: *Maritime Autonomous Surface Ships (MASS); Maritime Law; Product Liability; IMO; RCC; Port Regulation; Artificial Intelligence; Safe Manning; International Maritime Conventions. Limitation of Liability; AI Decision-Making.*

Resumen. El fenómeno de los Buques Autónomos (MASS) representa una de las transformaciones más profundas en la industria marítima, cuestionando los paradigmas tradicionales de seguridad, responsabilidad y supervisión normativa. Esta investigación sostiene que la asignación de la responsabilidad derivada de daños ocasionados por los MASS debe basarse primordialmente en un modelo de *responsabilidad por producto*, trasladando el peso hacia fabricantes, integradores, programadores y proveedores de sistemas críticos, sin excluir deberes claros para armadores y operadores. Asimismo, desarrolla un marco estructurado para delimitar la *responsabilidad de los Centros de Control Remoto (RCC)* y operadores en tierra, incorporando estándares de diligencia, criterios de imputación de fallas operativas, supuestos de responsabilidad compartida y su interacción con los regímenes de limitación de responsabilidad y seguros obligatorios. Mediante un análisis comparativo de los convenios internacionales, la Ley de Navegación y Comercio Marítimos, así como de los estudios exploratorios de la OMI sobre vacíos regulatorios, la tesis propone un modelo de responsabilidad por producto como vía idónea para distribuir riesgos y obligaciones en operaciones de MASS. Se demuestra que obligaciones tradicionales como la navegabilidad, el cumplimiento de regulaciones y la atribución de culpa resultan insuficientes frente a buques sin tripulación o controlados a distancia. Para cerrar esa brecha, se plantea un sistema en el que los fabricantes, programadores y operadores asuman responsabilidades más definidas, respaldadas por seguros obligatorios y mecanismos de armonización internacional. Más allá del análisis teórico, este trabajo ofrece un *mapa práctico de adaptación legislativa* para los Estados y la OMI, orientado a armonizar normas internacionales, anticipar desafíos éticos, contractuales y extracontractuales, y garantizar un equilibrio entre seguridad, innovación y rendición de cuentas en la era de la navegación autónoma. En ese sentido, se configura como una *guía jurídica para los legisladores y responsables de políticas públicas* que buscan regular de forma efectiva los MASS.

Palabras clave: *Buques Autónomos (MASS); Derecho Marítimo; Responsabilidad por Producto; Centros de Control Remoto (RCC); Organización Marítima Internacional (OMI); Limitación de Responsabilidad; Inteligencia Artificial; Dotación Mínima de Seguridad; Convenios Marítimos Internacionales; Regulación Portuaria.*

LIST OF ABBREVIATIONS

AI – Artificial Intelligence

CMI – Comité Maritime International

COLREGs – International Regulations for Preventing Collisions at Sea

FAL – Facilitation of International Maritime Traffic

ILO – International Labour Organization

IMO – International Maritime Organization

ISPS – International Ship and Port Facility Security Code

LLMC – Convention on Limitation of Liability for Maritime Claims (1976)

LNCM – Ley de Navegación y Comercio Marítimos

MNCL – Maritime Navigation and Commerce Law

MARPOL – International Convention for the Prevention of Pollution from Ships

MASS – Maritime Autonomous Surface Ships

MLC – Maritime Labour Convention

MSC – Maritime Safety Committee

MSC.1-Circ.1638 – Circular 1638 of the Maritime Safety Committee on the Regulatory Scoping Exercise for MASS

PTSD – Post-Traumatic Stress Disorder

RCC – Remote Control Center

RSE – IMO Regulatory Scoping Exercise

SAR – Search and Rescue

SEMAR – Secretaría de Marina

SOLAS – International Convention for the Safety of Life at Sea

STCW – International Convention on Standards of Training, Certification and Watchkeeping for Seafarers

UN – United Nations

UNCLOS – United Nations Convention on the Law of the Sea

YB – Yara Birkeland

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INTRODUCTION

On a fog-covered morning, the YV Horizon, a fully autonomous level 4 maritime autonomous surface ship (MASS), departs from the Port of Rotterdam towards Veracruz, Mexico, transporting a cargo worth 500 million euros. Unlike traditional vessels, there is no captain at the helm and no crew on board. Instead, it is guided by an artificial intelligence (AI) system supported by a remote operation center (RCC) thousands of miles away. With its advanced sensors, automated collision avoidance software, and cybersecurity protections, the ship is presented to the industry as a symbol of efficiency, reduced operational costs, and freedom from human error. Yet, halfway through its journey, the vulnerabilities of such a highly intellectual product are revealed.

Even though safe from traditional piracy, suddenly a sophisticated cyberattack disables its systems. The ship's transmitter goes silent, the location tracker is turned off, and the course shifts drastically; the first large-scale hijacking of an autonomous vessel has begun. In land, the operator of the RCC and the owner of the vessel (knowing how much that cargo is worth) contact their lawyers, but get a response far from clear. International conventions are drafted under the assumption that ships would always be manned by a captain and with a crew present, so they fail to adapt to the new reality.

Under the International Convention for Safety of Life at Sea (SOLAS), distress protocols require intervention on board, but here, no crew is present to activate them. The United Nations Convention on the Law of the Sea (UNCLOS) requires flag States to exercise jurisdiction and control over vessels, yet the flag State in this case has no domestic legislation regulating incidents involving MASS.

As the hijackers achieve changing the course of the YV Horizon, the situation escalates; the vessel has just identified another merchant ship on a collision course. Under the Convention on the International Regulations for Preventing Collisions at Sea (COLREGs), vessels must act in accordance with the flexible principle of "good seamanship." However, the AI cannot evaluate moral and ethical considerations. Should it prioritize avoiding damage to life aboard the traditional vessel, even if this means sacrificing

millions of euros worth of cargo and creating a massive contamination due to the contents of the same? Or should it protect its cargo in strict compliance with programmed algorithms, disregarding the human dimension and creating a life-or-death situation? This reveals the limits of entrusting machines with decisions that law and custom historically left to human judgment.

The consequences of the hijacking do not remain confined to the open sea. As the ship veers south toward the Caribbean, a coastal State invokes national security to justify deploying naval forces, while other States hesitate to act, citing sovereignty concerns and the absence of clear international rules on intervention against MASS. Hours later, the vessel collides with an offshore wind farm, severely damaging a critical source of renewable energy. The incident produces environmental harm, economic losses, and diplomatic disputes. Investigations begin, but accountability is uncertain. Should the shipowner be held liable under traditional carriage of goods regimes? Could liability instead fall on the manufacturer of the autonomous navigation system, consistent with the logic of product liability? Or might the flag State be responsible for failing to implement effective regulations, thereby breaching its obligations under international law?

The legal void is equally evident at the national level. Mexico, the destination country of the voyage, lacks specific provisions in its Maritime Navigation and Commerce Law (LNCM, for its initials in spanish.) to address hijackings or collisions involving MASS. The statute still presumes the presence of a master and crew on board and does not contemplate situations where AI replaces traditional decision-making. This absence of regulation not only limits the ability of Mexican authorities to respond effectively but also highlights the broader challenge faced by States worldwide: how to adapt domestic legislation to a technological reality that is moving faster than the law.

Even if the YV Horizon had a smooth voyage, the truth is that ports are not yet intelligent enough to receive a fully autonomous vessel (not even the most advanced ports like Rotterdam or Singapore are 100% prepared for it). An autonomous ship in an unprepared

port could face delays, safety risks, and extra costs due to the fact that the port itself lacks the systems and staff coordination to handle its cargo without a crew and immediate instructions.

This fictional scenario is a plausible projection of what may occur in the near future. It underscores how the deployment of MASS reveals the fragility of the current international legal system and the obsolescence of national frameworks that remain anchored in the paradigm of manned navigation. Issues such as cybersecurity vulnerabilities, ethical dilemmas in AI, jurisdictional conflicts, liability allocation, and the protection of critical infrastructure converge in a way that existing treaties were never intended to address.

The purpose of this thesis is to analyze these challenges systematically. From the international conventions and State laws applicable to maritime navigation, to proposing MASS as a complex product, so that liability can be determined. This model shifts responsibility from traditional actors, such as shipowners, to manufacturers and system designers who play a decisive role in the safety and reliability of autonomous technology. Finally, this thesis will propose a guideline for States to regulate MASS and, at the same time, adapt their ports so they can be compatible and prepared to receive such a change. Since the IMO does not regulate liability, this framework must be developed and adopted at the national and regional level, aligned with the IMO MASS Code to ensure technical consistency while reducing fragmentation.

Ultimately, this research seeks to show that the rise of autonomous vessels is not merely a technical challenge but a fundamental legal and ethical one. If the law fails to adapt, the risks of MASS will overshadow its benefits. If law evolves with foresight, however, the maritime industry can embrace innovation while ensuring safety, accountability, and environmental protection.

Chapter I

OVERVIEW OF MARITIME AUTONOMOUS SURFACE SHIPS

Covering over 70% of the Earth's surface, the ocean has always been the lifeblood of global commerce. Holding almost all the planet's water, it is not only vast in geography but essential to both ecological balance and economic survival (National Oceanic and Atmospheric Administration, 2018).¹ Since as early as the third century BCE, traders understood the value of maritime transport, relying on vessels, captains, and crews to carry goods across great distances. For centuries, that simple structure defined maritime law, yet today, that centuries-old paradigm stands on the verge of a profound transformation.

In the twenty-first century, the rise of MASS represents a turning point for the shipping industry. Departing from the traditional model, these vessels can navigate without a captain, helmsman, or crew, relying instead on artificial intelligence systems and remote monitoring. Their introduction signals a remarkable technological advance, yet it also opens the door to complex legal uncertainties, ethical dilemmas, and operational challenges that existing frameworks are not equipped to resolve.

Autonomy in the maritime context requires two things: first, the vessel must possess the technical capacity to make decisions independently, and second, it must be able to implement said decisions without human intervention (Ringbom, Røsæg, & Solvang, 2021)². Based on the degree of human involvement, MASS can be categorized into four distinct levels of autonomy, ranging from a system that requires constant oversight to vessels capable of fully independent navigation.

¹US Department of Commerce. "How much water is in the ocean? ". June 2018. Available online: NOAA. <<https://oceanservice.noaa.gov/facts/oceanwater.html#:~:text=The%20ocean%20covers%20more%20than,in%20glaciers%20and%20ice%20caps.>> (consult: March 28, 2025)

² Ringbom, Henrik., Røsæg, Erik, & Solvang, Trond. **Autonomous Ships and the Law**. 2nd ed. New York, Routledge, 2020/2021 (p.12) <https://www.routledge.com/Autonomous-Ships-and-the-Law/Ringbom-Rosaeg-Solvang/p/book/9780367692049?srsId=AfmBOoqp1m5dhllm8SRLBbzLmg9sTJmIqc7_XoLnnBLN-6il2rFyxzfl> (consult: March 28, 2025)

What only a decade ago seemed like a distant or even improbable scenario has now taken shape as a concrete reality. The industry is no longer asking whether MASS will enter the global fleet, but instead when, to what extent, and under which conditions its deployment will occur (Ringbom, H., Røsæg, E., & Solvang, 2021)³. This shift, however, is not without consequences. The transfer of responsibilities once carried out by seafarers introduces intricate legal questions that touch on every corner of maritime law: from determining the liability of shipowners, manufacturers, and software developers, to rethinking the application of collision regulations and assessing whether current insurance frameworks are adequate for this new era.

Despite the urgency of these questions, the academic literature on MASS remains comparatively limited. In the past five years, scholars and institutions have begun to explore the subject, yet comprehensive legal analysis is still rare. Only recently have detailed studies emerged that address the regulatory implications of autonomous navigation. At the international level, the IMO has responded by undertaking regulatory scoping exercises designed to identify gaps in existing conventions and to assess whether amendments or entirely new instruments will be necessary to accommodate MASS (Ringbom, H., Røsæg, E., & Solvang, 2021).⁴

A. MASS AND THEIR GROWING ROLE IN THE INDUSTRY

Maritime trade accounts for the transport of more than eighty percent of the world's goods, making it a cornerstone of global commerce (Javed, 2023).⁵ According to the United Nations Conference on Trade and Development (UNCTAD), global seaborne trade expanded by 2.4% in 2023, reaching 12.3 billion tons and recovering from the contraction experienced the previous year. Yet this recovery remains fragile, shaped by ongoing geopolitical tensions, climate-related disruptions, and vulnerabilities in critical chokepoints such as the Suez and

³ Ringbom Henrick, Røsæg Erik, & Solvang Trond, Op. Cit., p.3.

⁴ Idem., pp. 3-4.

⁵ Javed Amna. **Safe manning of ships in the era of new and emerging technologies**. World Maritime University Dissertations for the Award of Masters in Science in Maritime Affairs Degree. Sweden, World Maritime University, Oct. 2023 (p. 1).

Panama Canals. The consequences are felt most acutely by vulnerable economies, particularly small island developing States and least developed countries, which bear disproportionate costs from higher freight rates and rerouted vessels. Against this backdrop, the maritime sector is challenged not only to harness technological innovation for greater efficiency and profitability, but also to strengthen legal and regulatory frameworks capable of addressing these multifaceted risks. Developing an adaptive and resilient legal regime is therefore essential to sustaining a reliable and future-oriented maritime transport system (UNCTAD, 2024).⁶ It is within this fragile landscape that the emergence of MASS introduces both unprecedented opportunities and complex regulatory challenges.

MASS marks the beginning of a new era in ocean navigation and commercial shipping, where vessels can operate with minimal or even no human intervention. The IMO defines MASS as “*ships which, to varying degrees, can operate independently of human interaction*” (IMO, 2018). This definition emphasizes autonomy while raising immediate questions about liability, compliance, and safety. The promise of MASS lies in their potential to optimize fuel usage, lower operational costs, and reduce accidents caused on board; yet their deployment challenges the very foundations of maritime law.⁷

As part of its Regulatory Scoping Exercise, the IMO has identified four levels of autonomy for MASS, adopted through circular LEG.1/Circ.11. These levels establish a spectrum that ranges from vessels requiring human oversight to those capable of making and implementing decisions entirely on their own.

The first level, MASS 1.0, consists of vessels equipped with automated processes and decision-support systems, where crew members remain onboard with full command but rely on digital systems for tasks such as route optimization and monitoring mechanical functions. (International Maritime Organization, 2021)⁸.

⁶ UN Trade and Development. *Review of Maritime Transport*. 2024 Available online: UNCTAD <<https://unctad.org/publication/review-maritime-transport-2024>> (consult: April 13, 2025)

⁷ International Maritime Organization. *Autonomous Shipping*. 2018. Available online: IMO <<https://www.imo.org/en/mediacentre/hottopics/pages/autonomous-shipping.aspx>> (consult: April 13, 2025)

⁸ International Maritime Organization. *Regulatory Scoping Exercise for the Use of Maritime Autonomous Surface Ships*, LEG.1/Circ.11. 2021: Available online: IMO

MASS 2.0 refers to remotely controlled ships that still carry crew, allowing for remote operation while preserving the capacity for onboard human intervention when necessary. (International Maritime Organization, 2021).⁹

MASS 3.0 includes vessels that are fully remotely controlled with no personnel onboard, transferring all operational command to shore-based control centers. (International Maritime Organization, 2021).¹⁰

Finally, MASS 4.0 represents full autonomy, where artificial intelligence-driven systems are responsible for navigation, collision avoidance, and real-time decision-making without direct human supervision. (International Maritime Organization, 2021).¹¹

These categories are not rigid. A vessel may switch between levels depending on the operational context, for example, navigating autonomously in open seas but reverting to remote control when approaching congested ports. The distinction between transferring crew functions to RCCs and substituting them with automated systems is crucial: the former raises questions of manning and supervision, while the latter raises entirely new issues of liability when machines replace human judgment.

For this thesis, the analysis will focus primarily on Levels 3 and 4, where no crew is present onboard. These levels present the most significant legal challenges regarding liability, seaworthiness, and safety obligations. Levels 1 and 2 are acknowledged as transitional stages, but their legal implications largely remain within existing frameworks given the continued presence of crew.¹²

The concept of autonomy in maritime navigation requires careful differentiation between two distinct situations: the transfer of crew functions to operators on shore and the

<[https://wwwcdn.imo.org/localresources/en/MediaCentre/HotTopics/PublishingImages/Pages/Autonomous-shipping/LEG.1-Circ.11%20Outcome%20Of%20The%20Regulatory%20Scoping%20Exercise%20And%20Gap%20Analysis%20Of%20Conventions%20Emanating%20From...%20\(Secretariat\).pdf](https://wwwcdn.imo.org/localresources/en/MediaCentre/HotTopics/PublishingImages/Pages/Autonomous-shipping/LEG.1-Circ.11%20Outcome%20Of%20The%20Regulatory%20Scoping%20Exercise%20And%20Gap%20Analysis%20Of%20Conventions%20Emanating%20From...%20(Secretariat).pdf)> (consult: April 13, 2025) (Annex, p. 2).

⁹ Idem

¹⁰ Idem

¹¹ Idem

¹² * The IMO defines four levels of autonomy in LEG.1/Circ.11. This thesis concentrates on Levels 3 and 4, where autonomous operations are conducted without crew onboard, as these raise the most pressing regulatory and liability questions.

substitution of those functions by on-board automated systems. While the former involves remote control rather than genuine autonomy, the latter raises entirely different legal and operational questions, since it involves machines making navigational decisions once reserved for humans. At the same time, the notion of autonomy cannot be confined to rigid binary categories. In practice, vessels may operate with reduced crews or be temporarily unmanned for certain segments of a voyage. Likewise, autonomy in navigation often lies on a spectrum; key tasks may be performed automatically, but intervention may remain available through supervisory roles or activation when pre-set thresholds are exceeded.

This spectrum reveals the need for a more refined conceptual framework that reflects the operational realities of MASS. Such clarification is crucial both for academic debate and for international regulation, since it ensures a consistent terminology while shedding light on the range of legal challenges involved, from safety and security under public law to liability and insurance under private law (Ringbom, H., Røsæg, E., & Solvang, 2021).¹³ For greater clarity, *Figure 1* provides a simplified chart that visually illustrates the concepts discussed above.

¹³ Ringbom Henrick., Røsæg Erik, & Solvang Trond, Op. Cit., p.8

Name	Definition (Proposed Maritime Autonomy Framework)	Who is in Control? Sustained operational task	Who takes over control? Fail Safe Operational Task	System Capability
No Autonomy	All aspects of operational tasks perform by human operator even when enhanced with warning or intervention system. Human operator safely operates the system at all time. (e.g. Select pumps)	 Manual		n/a
Partial Autonomy	The targeted operational tasks perform by human operator but can transfer control of specific sub-tasks to the system. The human operator has overall control of the system and safely operates the system at all time. (e.g. start engine sequence)	 Automation		Some Operational Tasks
Conditional Autonomy	The targeted operational tasks perform by automated system without human interaction and human operator perform remaining tasks. Human operator is responsible for its safe operation.	 Semi-Autonomous		Majority of Operational Tasks
High Autonomy	The targeted operational tasks perform by automated system without human interaction and human operator perform remaining tasks. System is responsible for its safe operation. (e.g. PMS, DP)	 Semi-Autonomous		Majority of Operational Tasks
Full Autonomy	All operational tasks perform by an automated system under all defined conditions.	 Full Autonomous		All Operational Tasks

Figure 1. Relationship between MASS development and the degree of automation.

Copied from (Iwanaga. S, 2019) ¹⁴

The categorization of autonomy levels is not merely technical but carries direct legal consequences. At Levels 1 and 2, liability can still be attributed to masters, crew, or RCC operators. At Levels 3 and 4, where no crew is present and algorithms make independent choices, the allocation of responsibility becomes highly uncertain. If a collision occurs, should liability fall on the shipowner, the software developer, the manufacturer of the sensors, or the RCC supervising multiple ships at once? International rules such as COLREGs assume human seamanship and judgment, and thus their foundation is undermined when decisions are made by AI (Ringbom, H., Røsæg, E., & Solvang, 2020).

When machines make operational choices, the foundation of these legal standards is undermined. Thus, the levels of autonomy are directly linked to the allocation of responsibility: the higher the autonomy, the more the traditional liability structures of

¹⁴ Figure 1. Relationship between MASS development and the degree of automation. Iwanaga, S. Legal Issues Relating to the Maritime Autonomous Surface Ships' Development and Introduction to Services. **Master's dissertation, World Maritime University.** 2019. (p.10)

maritime law are challenged, creating pressure for new frameworks capable of addressing failures not of human judgment but of algorithms and automated processes.

Within this debate, Remote Control Centers (RCCs) have become an essential part of the discussion. These shore-based facilities allow operators to monitor vessel performance, oversee navigation, and assume control if necessary. They represent a transitional mechanism, bridging the gap between traditional seamanship and fully automated decision-making. While RCCs remain central at lower levels of autonomy, where human oversight is indispensable, their role fades at level 4, where the vessel functions independently without external intervention.

Closely connected to the role of RCCs is the issue of safe manning. International frameworks such as the STCW Convention have long required vessels to maintain a minimum crew to ensure safety and compliance. Yet these provisions have not evolved in step with digitalization. Current rules remain broad, offering only general guidelines and leaving owners and operators with considerable discretion, sometimes at the expense of safety (Javed, A. 2023)¹⁵. If a ship is monitored and directed entirely from an RCC, does this arrangement fulfill manning requirements? Should RCC personnel be considered crew for legal purposes? The lack of clarity in international law creates a regulatory vacuum that has yet to be addressed.

This tension is not merely theoretical. The YARA Birkeland in Norway, recognized as the world's first fully electric autonomous container vessel, demonstrates how MASS can reduce reliance on road transport while supporting sustainability goals (Javed, A. 2023)¹⁶. However, by reducing or even eliminating onboard crews, such projects also shift responsibility for compliance and emergency response onto shipowners, RCC operators, and technology developers.

¹⁵ Javed Amna, Op. Cit., pp. 2–3.

¹⁶ Javed Amna, Op. Cit., p. 3.

For these reasons, many scholars argue that the legal definition of “safe manning” requires rethinking. It can no longer be framed exclusively around the number of crew physically present on board but should instead be understood as a hybrid concept that incorporates both human oversight (whether exercised at sea or through an RCC) and the reliability of technological systems. Such a redefinition would not only align the law with the realities of MASS operations but also provide a clearer foundation for allocating liability. Other commentators, however, caution that stretching the concept too far risks undermining long-standing safety principles, suggesting instead that entirely new standards may be preferable. This thesis contends that redefining safe manning is not only viable but necessary, as it offers a practical means to close regulatory gaps while ensuring that safety obligations evolve in step with technological change.

B. CHALLENGES TO TRADITIONAL MARITIME REGULATIONS AND LIABILITY STRUCTURES

Maritime law has historically relied on a well-defined framework in which liability and responsibility were allocated among shipmasters, shipowners, crew members, and flag States. This system presupposed the presence of individuals on board who could make decisions related to navigation, compliance, and safety. The shipmaster, as the highest authority, was tasked with ensuring adherence to international rules, maintaining seaworthiness, and responding to emergencies, while shipowners bore vicarious liability for their crews. Insurance mechanisms complemented this structure by covering accidents, environmental damage, and cargo disputes.

The rise of MASS disrupts this established order. By reducing or removing human operators, autonomous systems erode the assumptions on which traditional liability is built. At higher levels of autonomy, where neither master nor crew is present, the chain of accountability becomes uncertain. The debate now extends beyond masters and owners to include potential responsibility for software developers, sensor manufacturers, and RCC operators supervising fleets from shore. Addressing these challenges requires not only

reconsidering liability allocation but also rethinking how insurance, collision regulations, and regulatory compliance can adapt to a new era of unmanned navigation.

Historically, maritime liability has been structured around clear doctrines relying on human accountability. The table below summarizes the conventional liability assignments in the shipping industry and how MASS disrupts them:

Traditional Liable Party	Role of Liability Assignment	Why MASS disrupts this model
Shipmaster	Responsible for all navigational decisions, emergency responses, and compliance with maritime laws.	AI-driven systems replace human decision-making, eliminating direct accountability.
Shipowner	Vicariously liable for the actions of the shipmaster and crew.	Absence of crew reduces clarity of liability; operational risks shift away from direct human control.
Crew Members	Ensure safe operations, cargo handling, and emergency preparedness.	No crew present in Level 4 MASS, removing human accountability.
Flag State	Ensures vessels under its jurisdiction comply with international maritime law.	Difficult to regulate a ship with no onboard personnel to inspect or monitor.

Table 1. Traditional Liability Party vs. MASS¹⁷

While this table illustrates the erosion of traditional roles, it does not capture the full scope of the disruption. New actors (remote operators (RCCs), system manufacturers, and software developers) are absent from traditional liability frameworks. Their growing centrality in MASS operations highlights the need for explicit recognition in domestic and regional law. The next table, therefore, expands the analysis by contrasting traditional liability parties with these emerging actors, underscoring where current frameworks remain silent and where reform is most urgently needed.

¹⁷ Table 1. Traditional Liability Party vs. MASS, own work

Actor	Role in MASS Operations	Regulatory Gap
Remote Control Centers	Provide continuous monitoring, operational oversight, and emergency intervention from shore.	Not recognized in conventions (e.g., COLREGs, STCW); no duties, training standards, or liability allocation.
Manufacturers	Design and integrate AI systems, sensors, and software critical to navigation and safety.	Entirely outside maritime law; liability excluded from limitation conventions; accountability only under fragmented domestic product liability regimes.
Insurers	Cover shipowner risks, cargo, and liability exposure.	Traditional insurance excludes AI/software defects; compulsory insurance for MASS accidents not yet mandated.

*Table 2. Emerging Actors*¹⁸

To achieve meaningful regulatory adaptation, it is essential to examine the broader challenges that MASS pose to existing conventions, particularly regarding enforcement and compliance. Liability debates dominate the academic discussion, but the absence of a unified framework complicates the recognition and operational integration of MASS. Current maritime law, drafted under the assumption of human presence, struggles to accommodate autonomous operations, raising pressing questions about monitoring, control, and accountability.

Not all doctrines, however, face these difficulties in the same way. As Yang, Liang, Chae, and Baumler (2025) emphasize, the obligation of seaworthiness demonstrates a capacity to evolve through judicial interpretation rather than statutory reform. Their study highlights how seaworthiness is not confined to purely technical aspects of the vessel but also encompasses the carrier’s non-delegable duty of due diligence. Courts apply standards such as the “prudent owner test,” which allow the doctrine to adapt to new circumstances and technologies without the need for a redefinition. By contrast, other areas (such as the legal

¹⁸ Table 2. Emerging Actors, own work

status of RCCs or the liability of manufacturers) lack this flexibility and will require deliberate legislative intervention to ensure clarity and consistency in MASS operations.¹⁹

Maritime liability traditionally falls into three categories: civil, criminal, and administrative liability. Civil liability covers damages caused by a vessel, whether through collisions, pollution, or cargo loss, typically holding shipowners or operators responsible. Criminal liability applies in cases of gross negligence or unlawful conduct, exposing shipmasters, crew, or corporate entities to prosecution for serious violations such as failing to render assistance at sea or violating environmental laws. Administrative liability involves compliance with conventions such as UNCLOS, SOLAS, and MARPOL, enforced not only by flag States but also by port States through Port State Control (PSC) mechanisms. These mechanisms have worked for centuries because they assumed the presence of human actors on board who could be identified and held accountable.

With the arrival of MASS, that assumption no longer holds. If a fully autonomous vessel collides, pollutes or breaches international standards, it is no longer clear where accountability lies. The absence of real time human judgement complicates doctrines of negligence and intent, exposing gaps in the traditional liability structure. This thesis argues that these challenges demand a reconfiguration of maritime liability, one that incorporates product liability principles to ensure accountability remains clear, fair and aligned with the IMO MASS code and broader international practice. This proposal (treating MASS as a complex product for the purposes of liability limitation) will be developed further in a subsequent chapter.

C. EMERGING ISSUES IN MASS GOVERNANCE

In maritime law, limitation of liability has traditionally been tied to the tonnage of the vessel. This approach reflects the idea that a ship's carrying capacity broadly corresponds to

¹⁹ Yang, Z., Liang, X., Chae, C.-J., & Baumler, R. **Maritime Autonomous Surface Ships (MASS) – Regulation, Technology, and Policy**. Springer, Heidelberg, 2024. WMU Journal of Maritime Affairs 24, 339–342 (2025) (consult: April 13, 2025).

the potential scale of damage it could cause in cases of collision, pollution, or cargo loss. By linking liability limits to tonnage, international regimes have sought to strike a balance between compensating victims and ensuring that shipowners can obtain affordable insurance. Without such limits, the financial exposure of shipowners could become so great that maritime trade would be severely hindered.

A further challenge in the governance of MASS lies in the interaction between existing limitations of liability regimes and the uncertain distribution of responsibility among new actors. Traditional maritime law (shaped by instruments such as the 1976 Convention on Limitation of Liability for Maritime Claims (LLMC) and its 1996 Protocol) allows shipowners to cap their financial exposure for personal injury, property damage, or pollution. Under the 1996 Protocol, as amended in 2012, the liability limit for loss of life or personal injury on ships not exceeding 2,000 gross tonnage was set at 3.02 million Special Drawing Rights (SDR), with additional sums added according to tonnage, while property claims were capped at 1.51 million SDR plus increments. These mechanisms provide predictability and help keep insurance premiums at sustainable levels, ensuring that maritime trade is not disrupted. The system, however, assumes that liability can always be tied to human actors such as shipowners, masters, or crew.²⁰

These tonnage-based limits were designed with conventional ships in mind, balancing the shipowner's exposure with the need for accessible insurance coverage. Their direct application to unmanned MASS is far from straightforward, because the very premise of a human-operated vessel no longer exists.

Autonomous navigation destabilizes that assumption. If a MASS operating without crew were to collide with another vessel or cause pollution, the core issue would not be the size of the liability cap but identifying who the liable party should be. Should responsibility remain with the shipowner, even if navigation is carried out entirely by algorithms? Could liability extend to the software developers who coded the decision-making system, or to

²⁰ **Convention on Limitation of Liability for Maritime Claims (LLMC)**. IMO. London, Feb. 27, 1987. Available online: <<https://treaties.un.org/doc/Publication/UNTS/Volume%201456/volume-1456-I-24635-English.pdf>> (consult: June 23, 2025)

operators at RCCs who monitor voyages from shore? The LLMC and its Protocols were never designed with these actors in mind, creating a significant interpretative gap.

As scholars have noted, while limitation of liability is a cornerstone for maintaining insurability and commercial viability in shipping, the absence of explicit allocation of duties to software and AI stakeholders risks undermining the very balance that limitation seeks to preserve (Carey, 2024).²¹ For ports and insurers, this uncertainty raises practical concerns: without clear liability rules, MASS operations may be denied entry, or premiums may rise prohibitively, eroding the economic benefits of autonomy.

In 2025, the challenge is no longer theoretical. The industry is already witnessing the deployment of semi and fully autonomous vessels such as the Yara Birkeland. Yet, no international framework has clarified whether the existing limitation regime can stretch to cover AI-related accidents. Without reform, insurers may hesitate to underwrite MASS operations, or states may impose fragmented rules through port entry requirements. This reveals an urgent need to adapt the limitation of liability system, not by abandoning its foundational principles, but by extending its scope through domestic and regional reforms that recognize the novel actors and risks introduced by maritime digitalization.

1. Cybersecurity Risks on MASS Operations

As the maritime industry transitions toward greater automation and leaves behind human control, cybersecurity risks emerge as one of the most pressing threats to the safe and reliable operation of MASS. This issue alone could serve as the foundation for an entire thesis, as its complexity allows for an extensive, in-depth analysis spanning countless pages.

Although this thesis does not aim to provide an exhaustive technical analysis of cybersecurity or the training requirements of remote operators, it is impossible to ignore the central role that digital vulnerabilities play in the governance of MASS. As the level of automation increases, so too does the exposure to cyberattacks, with systems such as AIS

²¹ Carey Luci. **Pushing the Limits: How Limitation of Liability Will Apply to Maritime Autonomous Surface Ships**. NUS Centre for Maritime Law Working Paper. National University of Singapore, Singapore, June 2024. (pp. 1–2).

already demonstrating significant weaknesses due to their reliance on open-frequency broadcasts.

Unlike traditional piracy, where attackers physically board and seize control of a vessel, MASS can be hijacked remotely through cyber intrusions. Hackers may compromise AI-based navigation systems, reroute ships to unauthorized destinations, or disable propulsion and communications, leaving a vessel stranded at sea. Such risks are not speculative: the IMO itself has recognized that cyberattacks on maritime systems could trigger severe disruptions, particularly as MASS increasingly depends on interconnected digital platforms for navigation and operations. GPS spoofing exemplifies this risk, as false location signals can mislead autonomous ships into dangerous or restricted areas, creating legal disputes, safety hazards, and even geopolitical incidents.

Beyond physical risks, cyberattacks also produce psychological impacts on seafarers and remote operators. Even the fear of cyber intrusions fosters anxiety, distress, and a sense of being constantly monitored. Breaches that expose sensitive data or compromise safety systems can heighten stress levels and, in severe cases, contribute to post-traumatic stress disorder (PTSD). The traumatic aftermath of a successful attack can leave long-lasting mental health effects on maritime professionals. Another dimension is technostress, arising from overreliance on automation. MASS generates vast streams of digital data, which seafarers and RCCs must process simultaneously with manual oversight. (Javed, A. 2023) ²².

The governance challenge lies in determining liability for cyber incidents. Traditional frameworks allocate responsibility to human masters and crews, but MASS creates scenarios where hackers may exploit vulnerabilities in software, RCC oversight, or port communication systems. At present, neither the LLMC nor conventions like SOLAS impose clear duties on technology providers or RCCs for cyber breaches. As a result, port States are likely to play a pivotal role by conditioning MASS entry on proof of cybersecurity compliance, certification, and insurance coverage against cyber risks. This ensures that

²² Javed Amna, Op. Cit., p. 21.

liability is not left in a legal vacuum but is allocated through domestic regulation and port State enforcement.

2. Remote Control Centers (RCCs) and Liability in MASS Operations

The rise of Remote Control Centers (RCCs) marks one of the most significant shifts in the governance of MASS. At higher autonomy levels (3 and 4), vessels may operate with no crew onboard, shifting oversight, navigation, and emergency intervention functions to land-based RCCs. Staffed by trained operators, these centers serve as the human link in otherwise machine-driven operations. Yet, despite their growing importance, RCCs are absent from the language of international conventions such as COLREGs, STCW, and SOLAS. This regulatory silence generates uncertainty not only about their operational role but also about their liability in the event of an accident.

The IMO Legal Committee's Regulatory Scoping Exercise has acknowledged this gap. Existing conventions assume that human presence on board provides the basis for compliance and accountability, leaving no clear status for shore-based operators. Without explicit recognition, liability risks become fragmented. Courts may be forced to decide whether RCC personnel should be treated as crew members, agents of the shipowner, or independent professionals, a question that carries profound consequences for liability allocation in MASS operations.²³

Sharma notes that RCCs may assume "*competency obligations equivalent to seafarers*" (Sarma, 2019)²⁴, particularly where the safe operation of MASS depends on their vigilance and ability to intervene. Similarly, Javed observes that the absence of minimum training standards or certification requirements for RCC staff leaves operators unaccountable

²³ IMO LEG.1/Circ.11, 2021, Op. Cit., p. 2

²⁴ Sharma A.V. Raghav. **Maritime Autonomous Surface Ships: Caught Between the Devil's Advocate and the Deep Blue Sea**. World Maritime University Dissertations for the Award of Masters in Science in Maritime Affairs Degree. Sweden, World Maritime University, Nov. 2019. (consult: June 28, 2025) (p. 29).

under existing conventions, despite their responsibility for safety-critical functions (Javed, A. 2023)²⁵.

The practical challenge lies in liability allocation. If a collision occurs because an RCC operator fails to act on an alert, should liability rest with the shipowner, the RCC operator personally, or the company operating the RCC? Current doctrines of vicarious liability may prove inadequate, as shipowners no longer exercise direct control over the individual decision-makers who manage multiple vessels simultaneously.

The absence of RCC regulation not only undermines safety but also impacts insurance and port access. Limitation of liability regimes presuppose identifiable human actors; without a clear allocation to RCCs, insurers may refuse to underwrite risks or raise premiums prohibitively (Carey, 2024)²⁶. This exposes MASS operators to economic uncertainty and hinders their acceptance into global trade routes.

For this reason, port States are likely to become the first regulators of RCC liability. By conditioning MASS entry on proof of RCC certification, adequate liability insurance, and clear contractual allocation of responsibilities, ports can bridge the current legal vacuum. Such requirements would ensure that RCCs are recognized as integral to safe operations and held accountable for negligence, without waiting for the slow pace of international treaty reform. The framework for RCC liability should be at a national port level, contemplating the following:

- 1) **Legal Status:** RCCs are recognized in domestic law as operational equivalents of crew, subject to duties of care.
- 2) **Certification:** States to adopt training and licensing standards for RCC operators, modeled on STCW principles but adapted for remote oversight.
- 3) **Liability Allocation:** Direct liability imposed on RCC operators/companies for negligent oversight, with clear contractual apportionment between shipowner and RCC provider.

²⁵ Javed Amna, Op. Cit., p. 20.

²⁶ Carey Luci, Op. Cit., p.3

- 4) **Insurance:** Compulsory insurance covering RCC negligence, cyber breaches, and operator errors as a condition for port entry.
- 5) **Integration with Product Liability:** While manufacturers remain strictly liable for defective technology, RCCs bear responsibility for negligent human oversight, preserving a balance between human and technological accountability.

In summary, RCCs occupy a hybrid position: they are not seafarers in the traditional sense, but their oversight functions are so central that treating them as legally invisible is no longer tenable. The future of MASS liability depends on recognizing RCCs within domestic legal systems, ensuring their accountability through certification, liability rules, and compulsory insurance. This adaptation, implemented at the national and port level, would harmonize MASS operations with the IMO MASS Code's technical standards while addressing the unique governance challenges posed by shore-based control.

3. The Role of AI in Decision-Making in MASS Navigation

The highest levels of autonomy in MASS replace the seafarer's judgment with artificial intelligence. These systems can process vast amounts of data, anticipate scenarios, and respond in real time, often faster and more accurately than a human mind. They learn from each voyage, becoming more efficient with experience. Still, despite these advantages, a persistent challenge remains: AI cannot replicate human intent, moral reasoning, or situational awareness, nor can it justify the choices it makes other than the algorithm it was programmed to follow.

This shift marks a profound change in maritime navigation. Tasks once dependent on human judgment (route planning, collision avoidance, speed adjustments, and compliance with international regulations) are now performed by algorithms and machine learning models. While this transition promises efficiency and reduced liability risks, it also creates complex legal and ethical dilemmas. Without intent or the capacity to explain its decisions,

AI complicates the allocation of responsibility when accidents occur, raising difficult questions for regulators, courts, and the industry alike.

According to the Allianz Global Corporate & Specialty Global Claims Review, human error has been the number one cause of incidents in the maritime sector. Between 2011 and 2016 alone, it has presented a loss of 1.6 billion dollars.²⁷ The figure below demonstrates this in a visual way.

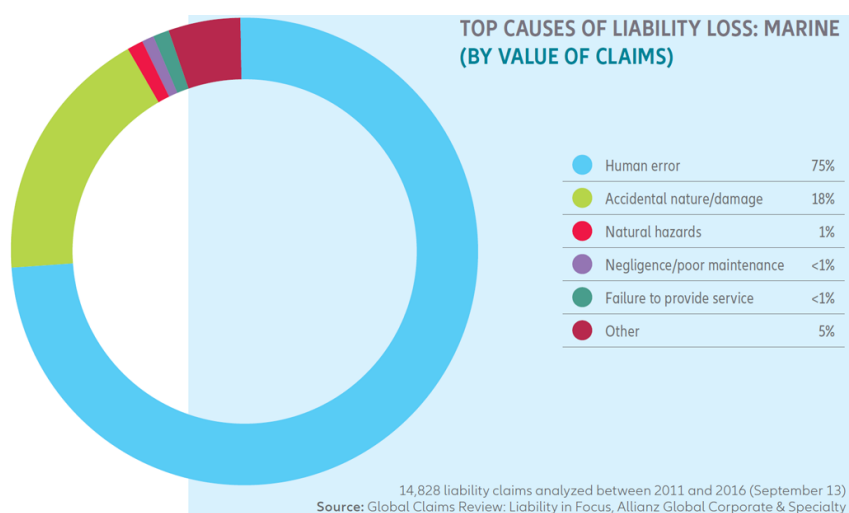


Figure 2. Top Causes of Liability Loss: Marine

Copied from (Global Claims Review: Liability in Focus, Allianz Global Corporate & Speciality)²⁸

As noted in the Global Claims Review: Liability in Focus by Allianz Global Corporate & Specialty, a significant factor in this is the “normalization of risk” in decision-making, particularly under pressure. Captain Andrew Kinsey, Senior Marine Risk Consultant at Allianz, explains that:

²⁷ Allianz, “Casualties – Behavioral and Cultural Risks Still Needs Addressing”, 2018 Available online: [Allianz < https://commercial.allianz.com/news-and-insights/expert-risk-articles/casualties-behavioral-and-cultural-risk.html>](https://commercial.allianz.com/news-and-insights/expert-risk-articles/casualties-behavioral-and-cultural-risk.html) (consult June 28, 2025)

²⁸ Figure 2 copied from: Allianz, Op. Cit. p.1

“It’s human nature. Many mariners have done it. They are under pressure, take a shortcut once that may not be the safest way to go, and get away with it. This then becomes the norm under stressed conditions.” (Allianz Global Corporate & Specialty, 2016)²⁹

Automation introduces a different challenge: the capacity of artificial intelligence to adapt to unpredictable and high-pressure maritime environments., AI operates within programmed parameters or learned algorithms. Its effectiveness depends on how well it can process complex, real-time variables (such as sudden weather shifts, unexpected vessel behavior, or navigational hazards) and respond appropriately.

As scholars note, AI’s “intelligence” in this context refers not to human-like reasoning but to its ability to accomplish complex goals through either pre-programmed rules or machine learning techniques (Ringbom, Røsæg, & Solvang, 2021)³⁰. The real legal and ethical question is whether MASS should be permitted to continue learning after deployment, refining their decision-making at sea, or remain restricted to pre-validated algorithms.

Despite these capabilities, AI decision-making is fundamentally different from human judgment. Unlike a captain who can assess nuanced situations based on experience, intuition, and ethical considerations, AI systems operate strictly within the boundaries of their programming. This poses several challenges, such as the inability to maintain good seamanship, as outlined in Rule 8(a) of the International Regulations for Preventing Collisions at Sea (COLREGs)³¹, Action to Avoid Collision, and it involves context-dependent decision-making and adaptability. AI lacks the ability to interpret ambiguous maritime scenarios, such as how to respond to a ship displaying erratic movements or making last-minute course changes³².

Another challenge is the failure to predict unconventional behavior as AI operates based on pattern recognition data, making it less adept at anticipating a seaman’s unpredictability like a small fishing boat making an illegal maneuver in restricted waters. But perhaps the

²⁹ Loc. Cit.

³⁰ Ringbom Henrick, Røsæg Erik, & Solvang Trond, Op. Cit., p.10.

³¹ **Convention on the International Regulations for Preventing Collisions at Sea (COLREGs) 1972**. IMO. London, 1972. Available online: < <https://www.samgongustofa.is/media/log-og-reglur/COLREG-Consolidated-2018.pdf> > (consult: June 23, 2025)

³² International Maritime Organization. “*Convention on the International Regulations for Preventing Collisions at Sea (COLREGs) 1972*”. Available online: **IMO** < <https://www.imo.org/en/about/conventions/pages/colreg.aspx> > (consult: June 13, 2025)

most important challenge the AI faces in replacing humans is the ethical dilemma, if an AI-controlled vessel is faced with two dangerous choices, for instance, colliding with another ship or running aground in an environmentally protected area, how does it prioritize safety? Should AI prioritize lives, environmental protection, or economic interests? Unlike captains, AI lacks moral reasoning and cannot assess the broader ethical consequences of its decisions.

This limitation becomes critical in high-stakes maritime scenarios, where ethical judgment is often necessary to balance legal compliance, environmental responsibility, and the protection of life. This incapacity to exercise context-sensitive discretion underscores the risks of delegating complex navigational and safety-related decisions to AI. It further illustrates the need for legal frameworks that address not only the operational functions of MASS, but also the normative role previously held by officers in interpreting and acting upon legal and ethical imperatives. To illustrate the potential dangers of unregulated AI decision-making in MASS, consider the following scenario:

A fully autonomous cargo vessel (level 4 autonomy), registered under a flag state that allows Level 4 autonomy, is traveling through international waters. The ship is programmed to take the shortest route to its destination, optimizing fuel efficiency and avoiding bad weather. However, due to AI's misinterpretation of regulatory restrictions, the vessel inadvertently enters an environmentally protected maritime zone where commercial shipping is strictly prohibited.

As the ship crosses into these restricted waters, it is detected by a coastal state's surveillance system. Authorities issue a warning, but because the ship has no crew, the AI fails to recognize the severity of the situation. The autonomous system continues its course, believing that taking an alternate route would increase fuel consumption and delay delivery, which its optimization algorithm deems "unfavorable."

Soon, the coastal state deploys a naval vessel to intercept the autonomous ship, suspecting illegal activity. However, the AI, designed to avoid confrontation and follow pre-set risk calculations, misinterprets the approach as a navigational hazard and performs an evasive maneuver that nearly results in a collision.

The situation escalates into a diplomatic conflict, as the coastal state claims that the ship violated its sovereignty and engaged in "reckless navigation." In the aftermath, several legal and ethical questions arise: Who is liable for the violation? The shipowner, AI developer, or flag state? Can the AI be held legally accountable, or does liability default to operators despite their lack of direct involvement? Should AI be programmed to prioritize legal compliance over operational efficiency, even at financial cost?

This scenario demonstrates the urgent need for clear regulations defining AI accountability in maritime operations. Without a legal framework that establishes liability, compliance requirements, and emergency override mechanisms, MASS could create unprecedented challenges in international maritime law.

4. Vessel-Port Communications

The integration of Maritime Autonomous Surface Ships (MASS) into international trade requires a redefinition of vessel–port communications. Traditionally, ports have relied on human-mediated channels such as shipmasters, port captains, and customs officials to ensure safe and efficient entry, clearance, and cargo handling. However, with the emergence of highly autonomous ships, particularly at Levels 3 and 4, the interaction between vessels and ports will increasingly depend on digital platforms and automated systems. This shift makes it essential to examine how “smart ports” can serve as the necessary infrastructure for the future of MASS operations.

Communication between ships and ports is more than a logistical necessity; it represents the foundation of maritime safety, legal accountability, and trade facilitation. The FAL Convention already seeks to streamline and standardize this process by reducing the administrative burden of documentary requirements for international shipping.³³ Yet, MASS introduces new challenges: how will a port exchange safety or clearance information with a

³³ **FAL Convention: Convention on Facilitation of International Maritime Traffic, 1965.** IMO. London, April 9, 1965. Available online: < <https://www.imo.org/en/ourwork/facilitation/pages/falconvention-default.aspx> > (consult: June 23, 2025)

vessel that has no crew on board? In the absence of a shipmaster, should the responsibility fall on Remote Control Centers (RCCs), automated reporting systems, or a hybrid of both?

The Manual de Puertos Inteligentes highlights that smart ports go beyond adopting digital tools; they create ecosystems where technology, governance, and community converge to achieve efficiency, safety, sustainability, and integration with urban environments (Fundación Valenciaport. 2020)³⁴. MASS cannot be integrated into global supply chains without ports capable of supporting real-time digital interaction, secure cargo processing, and automated traffic management.

A key advantage of smart ports lies in their ability to optimize operations through data-driven logistics, enabling faster vessel turnaround, predictive maintenance, and efficient cargo allocation. Yet, the manual stresses that ports must also adopt a holistic perspective that incorporates sustainability, environmental protection, and social considerations. This multidimensional approach is particularly relevant for MASS, as their unmanned nature requires ports not only to adapt technologically, but also to ensure that legal responsibilities remain clearly allocated between human and non-human actors.

Developing a smart port requires a strategic planning process that includes diagnostic studies of technological maturity, definition of long-term objectives, and measurable indicators to monitor progress. This process is crucial for MASS integration: ports need to assess whether their current digital infrastructure can accommodate autonomous ships that rely on encrypted communication, AI-based scheduling, and seamless customs clearance without physical crew interaction.

However, significant barriers persist, including high investment costs, lack of skilled personnel, and fragmented initiatives (Fundación Valenciaport. 2020).³⁵ These challenges raise concerns about the digital divide: while large global hubs such as Rotterdam, Singapore, and Shanghai may adapt rapidly, smaller regional ports may lack the resources to meet MASS

³⁴ Fundación Valenciaport. “Manual de puertos inteligentes: Estrategia y hoja de ruta”. Banco Interamericano de Desarrollo. 2020. (consult: May 3, 2025) (pp. 7, 9).

³⁵ Idem. pp. 14, 17, 23, 24.

requirements. This inequality risks creating a two-tiered maritime system, where only technologically advanced ports can accommodate autonomous vessels, thereby undermining the principle of non-discriminatory access that underpins international trade law.

Regulation, therefore, becomes indispensable. As ports become more digitized, they are increasingly vulnerable to cyber threats, operational risks, and misuse of data. MASS compounds this risk, as vessels could be hacked remotely and manipulated during port approaches.

The ISPS Code and SOLAS Chapter XI-2 already establish a global framework for maritime security, emphasizing cooperation among governments, port facilities, and companies to detect and prevent threats. However, these frameworks must evolve to address AI-specific vulnerabilities such as GPS spoofing, system hacking, or AI manipulation. Regulation must also ensure fair competition and transparency by mandating open and interoperable digital platforms, preventing monopolistic control of data. Similarly, environmental sustainability must be embedded into the regulatory agenda to ensure that ports align with international climate goals, reduce emissions, and integrate into sustainable urban planning. Social adaptation is equally vital: as smart ports demand new skills, the law must support workforce training, labor protections, and safety standards.

Although the legal recognition of RCCs remains unresolved, their role in vessel–port communications cannot be ignored. In the absence of a shipmaster, RCCs may act as intermediaries responsible for transmitting clearance requests, safety declarations, and cargo data to port authorities. An additional layer of complexity arises from jurisdictional conflicts: a MASS flying the Mexican flag, operated from an RCC in the Netherlands, entering a port in Singapore raises the question of which authority has the final say in the event of miscommunication or cyber interference. This illustrates why vessel–port communications must be explicitly regulated under international conventions such as FAL and SOLAS, updated to accommodate remote and AI-driven interactions.

From a forward-looking perspective, smart ports should be seen as the gatekeepers of MASS integration. Their ability to provide secure, standardized, and transparent communication channels will determine whether MASS can operate safely and legally in international waters. The evolution of port community systems into interconnected digital ecosystems is not just a matter of efficiency; it is essential for safeguarding liability frameworks, ensuring equality of access, and protecting maritime security.

Without a coherent regulatory framework, the risk is that MASS will be integrated unevenly, creating fragmentation and vulnerabilities in the global maritime system. International cooperation (anchored in the FAL Convention, ISPS Code, and IMO-led initiatives) is indispensable for building the next generation of ports capable of meeting the demands of autonomous shipping (Fundación Valenciaport. 2020)³⁶.

This centrality of vessel–port communications underscores why port States will become pivotal actors in the governance of MASS, since entry requirements and communication protocols provide a natural enforcement point for liability, certification, and insurance obligations.

³⁶ Fundación Valenciaport, Op. Cit., pp. 40, 41, 50.

Chapter II

REGULATORY FRAMEWORK UNDER IMO: GAPS AND CHALLENGES

The rapid advancement of MASS has ushered in a new era of innovation in global shipping. However, this technological leap has outpaced the evolution of international maritime regulations, creating a regulatory void that raises significant legal and operational challenges. While the International Maritime Organization (IMO) has undertaken initial steps to address the implications of autonomous shipping, the existing regulatory framework remains deeply rooted in the traditional concept of human-operated vessels.

The fundamental principles of international maritime law, established through instruments such as UNCLOS, SOLAS, COLREGs, and STCW, presuppose the presence of onboard oversight. These rules struggle to accommodate the complexities of MASS, leaving substantial gaps in governance, liability, and enforcement mechanisms.

This chapter examines the existing international regulatory framework governing MASS, identifying the limitations that hinder its effective application to autonomous vessels. The objective is to underscore the pressing need to distinguish between the IMO's role in setting global technical and operational standards and the responsibility of States to develop liability frameworks. While the absence of a unified global legal framework has led to fragmentation, this reflects the structural reality that liability and enforcement will primarily evolve at the domestic and regional level. Ports, as the points of intersection between international rules and national law, illustrate this duality by enforcing IMO technical standards while requiring domestic compliance in matters of liability and insurance.

The necessity of a well-defined regulatory structure is paramount to ensuring the safe, secure, and efficient integration of MASS into the global maritime industry. Without clarity in the interaction between international conventions and domestic regimes, inconsistencies may lead to jurisdictional disputes, operational inefficiencies, and increased risks in autonomous shipping. By identifying the regulatory gaps within the IMO framework, this

chapter lays the foundation for subsequent sections, which will argue for domestic and regional liability adaptation aligned with the IMO MASS Code.

A. EXISTING INTERNATIONAL
MARITIME REGULATIONS AND
THEIR LIMITATIONS

The regulation of international maritime activities is primarily based on a series of legal instruments developed to ensure the safety, security, and environmental protection of global shipping. These conventions, administered by IMO, set standards for ship design, operation, and crew requirements. However, the introduction of MASS challenges the applicability of these existing legal frameworks.

The IMO is the specialized agency of the United Nations responsible for regulating international shipping. Established in 1948 through the Convention on the International Maritime Organization, its primary mandate is to create a comprehensive legal framework to promote maritime safety, environmental protection, and navigational efficiency. The IMO plays a crucial role in ensuring that global shipping operates under uniform regulations, mitigating risks associated with maritime transport while facilitating international trade. Through its various conventions, protocols, and codes, the IMO has developed an extensive regulatory network that governs nearly every aspect of maritime operations.

“...the IMO, like the other specialized agencies, is not formally subordinated to the UN, but rather has been “brought into relationship” with the UN by an agreement with it under Articles 57 and 63 of the UN Charter, and reports each year to the UN’s Economic and Social Council on its activities. “ (Batz Yvonnee, 2018).³⁷

The IMO's regulatory scope encompasses a wide range of maritime issues, including vessel construction and design standards, crew qualifications, search and rescue operations, environmental protection, and liability frameworks. Among its most significant conventions are the SOLAS, which establishes safety requirements for merchant ships; COLERGs, which provide navigational rules to avoid maritime accidents; MARPOL, which regulates marine

³⁷ Batz Yvonnee. **Maritime Law**. 4th ed. Oxon, Routledge. 2015/2018. (p.338)

pollution and emissions; and STCW, which sets global training standards for maritime personnel. These legal instruments, along with numerous codes and guidelines, form the foundation of international maritime governance and enforcement.

Despite its extensive regulatory reach, the IMO faces growing challenges in adapting its legal framework to accommodate new technological advancements, particularly the rise of MASS. The traditional assumptions underlying existing maritime laws are based on the presence of a crew responsible for navigation, watchkeeping, and emergency response. However, the introduction of MASS has disrupted this paradigm, raising questions about how these vessels should be regulated within the current legal framework. The IMO has acknowledged this issue and has undertaken a Regulatory Scoping Exercise for MASS, led by its Maritime Safety Committee (MSC), to assess the extent to which existing conventions apply to autonomous vessels (MSC.1-Circ.1638).³⁸

The findings reveal that while some provisions may be adaptable, many require significant amendments to ensure that MASS can operate safely and legally under international law.

One of the most pressing regulatory voids concerns the definition of key maritime terms. Current conventions lack clear definitions for “autonomous vessel,” “remote operator,” and “control center,” which are crucial for determining liability, responsibility, and compliance standards. This gap was explicitly recognized by the IMO through its Regulatory Scoping Exercise for the Use of Maritime Autonomous Surface Ships, formalized in document MSC.1/Circ.1638³⁹.

The circular outlines a comprehensive review of multiple IMO instruments and highlights that the absence of legal definitions for these terms creates ambiguity in the allocation of legal obligations and in the interpretation of maritime duties traditionally

³⁸ International Maritime Organization. “*Guidelines for trials of maritime autonomous surface ships (MASS)*.” IMO. 2016. (MSC.1/Circ.1638)” June 2021, Available online: **IMO** <

[https://wwwcdn.imo.org/localresources/en/MediaCentre/HotTopics/Documents/MSC.1-Circ.1638%20-%20Outcome%20Of%20The%20Regulatory%20Scoping%20ExerciseFor%20The%20Use%20Of%20Maritime%20Autonomous%20Surface%20Ships...%20\(Secretariat\).pdf](https://wwwcdn.imo.org/localresources/en/MediaCentre/HotTopics/Documents/MSC.1-Circ.1638%20-%20Outcome%20Of%20The%20Regulatory%20Scoping%20ExerciseFor%20The%20Use%20Of%20Maritime%20Autonomous%20Surface%20Ships...%20(Secretariat).pdf)> (Consult: May 15, 2025).

³⁹ Loc. Cit.

assigned to onboard crew. In particular, the document identifies the need to clarify who or what can be considered the "master" or "operator" of an autonomous vessel to ensure accountability under international maritime law. Furthermore, existing regulations assign accountability primarily to the shipmaster and crew, which becomes problematic when a vessel is controlled remotely or navigates without intervention. This gap complicates legal questions surrounding liability in cases of accidents, equipment failures, or environmental damages caused by MASS, highlighting the need for States to define liability rules for new actors such as RCCs and manufacturers.

While the IMO has taken steps to address these challenges, progress in establishing a comprehensive regulatory framework for MASS has been slow. The complexity of amending international treaties, coupled with the need for global consensus among member states, has resulted in regulatory uncertainty. To ensure the seamless integration of MASS into the global maritime industry, the IMO must continue its regulatory efforts to provide a cohesive set of technical and operational standards. However, liability and accountability issues will need to be addressed at the domestic and regional level, particularly through port State regulation and national legislation that complements the IMO MASS Code.

1. International Convention for the Safety of Life at Sea (SOLAS)

SOLAS is considered one of the most important international treaties regarding the safety of ships. According to the IMO, this convention was originally adopted in 1914 following the Titanic disaster, and since then has undergone revisions to make sure it is up to date with technological advances⁴⁰. The main objective of the convention is to specify standards for construction, equipment, and how vessels should be operated to ensure safety. Flag States (countries under which a ship is registered or "flags" the vessel for legal and regulatory purposes) need to enforce the maritime laws and all conventions applicable to vessels registered within their jurisdiction.

⁴⁰ **International Convention for the Safety of Life at Sea (SOLAS)**. IMO. London, November 1, 1974. Available online: < <https://www.imo.org/en/knowledgecentre/conferencesmeetings/pages/solas.aspx> >. (consult: May 6, 2025)

The current SOLAS Convention includes Articles that aim to ensure the obligations and safety, as well as procedures, and is divided into 14 chapters. Some of these chapters are particularly relevant for the legal framework of MASS as they govern the safety of navigation, liability, and security.⁴¹

CHAPTER	DESCRIPTION	MASS CHALLENGES
IV	Governs radio communications, distress signals, and emergency communications for ships at sea.	MASS must rely entirely on automated distress signaling, raising concerns about response efficiency and whether AI can assess emergencies accurately.
V	Establishes safety requirements for navigation, including voyage planning, bridge visibility, and the obligation to maintain a proper lookout.	MASS lacks onboard crew for traditional watchkeeping and decision-making, raising questions about how AI and remote operators can fulfill these requirements.
XI-2	Defines maritime security measures under the International Ship and Port Facility Security (ISPS) Code, focusing on threat prevention and response.	The convention does not currently address cybersecurity risks specific to autonomous vessels, leaving MASS vulnerable to hacking and GPS spoofing.

Table 3. SOLAS chapters and MASS challenges⁴²

The European Union has already begun addressing some of these vulnerabilities through initiatives such as the EU Cybersecurity Act and port-specific security directives, which require operators to adopt risk-based cybersecurity measures. Although these frameworks are not yet tailored to MASS, they illustrate how regional actors may move more quickly than the IMO to translate operational standards into enforceable obligations at the port and vessel level.

Recognizing these regulatory gaps, the IMO has undertaken a Regulatory Scoping Exercise for MASS to evaluate necessary amendments to SOLAS. Key areas of focus include redefining watchkeeping responsibilities, revising certification standards for remote operators, and developing robust cybersecurity measures for autonomous shipping. However, the IMO's work is limited to setting technical and operational standards, leaving liability and

⁴¹ International Convention for the Safety of Life at Sea (SOLAS). Op. Cit

⁴² Table 3. SOLAS Chapters and Mass Challenges, own work.

accountability questions unresolved. This creates legal uncertainty that States and port authorities will have to address domestically through liability rules and entry requirements.

Given the growing reliance on automation in the maritime industry, modernizing SOLAS is imperative to accommodate new technologies while maintaining safety standards. Without comprehensive updates to reflect the realities of autonomous shipping, MASS will continue to face regulatory ambiguity, hindering their large-scale deployment.

To illustrate the importance of SOLAS in the regulation of MASS, let's deep dive into the hypothetical case of the YV Atlas, a fully autonomous cargo vessel navigating through a heavily trafficked international shipping lane. The ship, designed to operate without intervention, relies entirely on AI-powered navigation systems to comply with collision avoidance protocols. However, due to a software malfunction in its decision-making algorithm, the vessel fails to recognize an incoming tanker, the KN Horizon, which is following conventional COLREGs-mandated maneuvering procedures.

With no onboard crew to take corrective action, the YV Atlas does not alter course in time, leading to a severe collision that results in significant environmental damage due to an oil spill. Investigations reveal that, while the autonomous ship was programmed to follow SOLAS Chapter V requirements, the failure of oversight led to a critical misjudgment in risk assessment. Further, liability disputes arise, as the ship's owner argues that the software developer, rather than the operator, should be held accountable for the accident.⁴³

This incident underscores the urgency of adapting SOLAS to clarify technical and operational duties, particularly with respect to watchkeeping, remote oversight, and response protocols. Yet liability, accountability, and the allocation of decision-making responsibilities cannot be resolved within SOLAS itself and must instead be developed by States, ideally in harmony with the IMO MASS Code. Without this dual approach, MASS operations present substantial safety risks that current law is ill-equipped to handle.

⁴³ International Convention for the Safety of Life at Sea (SOLAS). Op. Cit

2. International Regulations for Preventing Collisions at Sea (COLREGs)

COLREGs was established in 1972 by the IMO, and it governs navigational conduct to prevent collisions. COLREGs outline the rules of the sea so that every vessel follows the guidelines from signaling to maneuvering. In the case of MASS, COLREGs are vital as they regulate navigation, which, in this case, will be taken over by AI in the future. Nevertheless, the same issue is presented in this convention as the others that were previously mentioned: all of the rules or guidelines were made with the traditional structure of vessels operated by navigators.

COLREG includes 41 rules divided into six parts and four annexes.⁴⁴ The six parts are divided in the following way:

1. PART A – General
2. PART B – Steering and Sailing
3. PART C – Lights and Shapes
4. PART D – Sound and Light signals
5. PART E – Exemptions
6. PART F – Verification of compliance with Convention

From all the 41 rules distributed in the six parts, 7 stand out as they highlight the regulatory gaps in COLREGs regarding MASS navigation, situational awareness, and decision-making capabilities, reinforcing the need for updated legal provisions to address autonomous maritime operations.⁴⁵

RULE	DESCRIPTION	MASS CHALLENGES
Rule 2 – Responsibility	Holds shipmasters and crews accountable for safe navigation and avoiding collisions, even if following	MASS lacks human judgment and situational discretion, making it difficult for AI systems

⁴⁴Convention on the International Regulations for Preventing Collisions at Sea (COLREGs). Op. Cit

⁴⁵ IMO, Convention on the International Regulations for Preventing Collisions at Sea (COLREGs). Op. Cit

	the rules strictly would result in an unsafe situation.	to interpret ambiguous scenarios and prevent collisions based on context.
Rule 5 – Lookout	Requires that all vessels maintain a proper lookout using sight, hearing, and all available means to assess the risk of collision.	Requires that all vessels maintain a proper lookout using sight, hearing, and all available means to assess the risk of collision.
Rule 8 – Action to Avoid Collision	Specifies that any maneuver to avoid a collision must be taken in ample time and in accordance with good seamanship.	The concept of “good seamanship” is not well-defined for AI systems, and programming MASS to make legally sound and practical navigational decisions remains a challenge.
Rule 10 – Traffic Separation Schemes	Regulates vessel movements in traffic lanes, requiring ships to cross at right angles and avoid impeding other vessels.	MASS may face difficulties interpreting and reacting to human-operated vessels’ behavior within traffic separation zones, increasing the risk of operational conflicts.
Rule 14 – Head-on Situations	Requires ships to alter their course to starboard when approaching another vessel head-on.	Without human intuition, MASS may fail to recognize when a situation qualifies as head-on, particularly in cases where vessel behavior is unpredictable.
Rule 15 – Crossing Situations	Specifies that a vessel on the starboard side has the right of way and the give-way vessel must take appropriate action.	Autonomous ships must be programmed to comply with right-of-way rules but may struggle with vessels that do not follow COLREGs strictly, leading to unexpected encounters.
Rule 17 – Action by Stand-on Vessel	Allows the stand-on vessel to take evasive action if the give-way vessel does not maneuver appropriately.	MASS lacks the ability to communicate with other vessels as humans do, making it difficult to determine when to act as a stand-on vessel.

Table 4. COLREGS rules and MASS challenges ⁴⁶

Beyond these specific rules, the central challenge of applying COLREGs to MASS lies in the so-called “black box” problem of artificial intelligence. COLREGs presuppose that a master or crew can exercise judgment, discretion, and what the rules themselves call “good seamanship” when facing ambiguous navigational circumstances, making it difficult to determine the reasoning behind an evasive maneuver or a failure to act. This opacity complicates not only the international application of COLREGs but also the enforcement role

⁴⁶ Table 4. COLREGs rules and MASS Challenges, own work

of port States, which will need to decide how to assess MASS compliance before authorizing entry into congested waters.⁴⁷

Yet, as the Comité Maritime International has noted, autonomous navigation systems cannot be interrogated in the same way as actors, making it difficult to determine the reasoning behind an evasive maneuver or a failure to act. This opacity undermines the traditional negligence model, which depends on assessing whether a mariner acted reasonably in the circumstances. For this reason, scholars and practitioners increasingly suggest that a regime of strict liability, or even a reversal of the burden of proof, may be required to ensure accountability when MASS are involved in collisions, particularly under Rules 2 and 5, where the exercise of judgment is indispensable.⁴⁸

The application of COLREGs to MASS exposes key regulatory gaps that must be addressed for legal clarity and navigational safety. A major issue is the definition of a "watchkeeper" or "lookout." Can AI-based sensors replace perception? While advanced technology enhances situational awareness, its ability to interpret complex maritime environments remains uncertain.

Liability and accountability are also unresolved. If an autonomous vessel causes a collision, responsibility could fall on the shipowner, AI developer, or remote-control center, creating legal ambiguity. Similarly, maneuvering decisions become problematic, as AI lacks intuition and may struggle with the COLREGs' concept of "good seamanship."

The transition toward autonomous maritime operations demands that COLREGs evolve to accommodate AI-driven decision-making while ensuring navigational safety. However, since COLREGs are unlikely to be fundamentally amended in the near future, domestic frameworks will have to clarify how liability is allocated when AI fails to comply with navigational standards. Without such domestic adaptation, MASS will operate in an

⁴⁷ IMO, Convention on the International Regulations for Preventing Collisions at Sea (COLREGs). Op. Cit

⁴⁸ Comité Maritime International. "Report on a Survey of Current Issues relating to Remote Operation Centres" Available online: CMI. < <https://comitemaritime.org/work/mass/> >. (consult: July 6, 2025)

uncertain regulatory landscape, potentially leading to increased disputes, liability concerns, and operational inefficiencies.

3. International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers (STCW)

The STCW convention was adopted in 1978 by the IMO to establish a uniform set of training and competency requirements for seafarers. Its main goal is to ensure that all personnel responsible for ship operations possess the necessary qualifications to perform their duties safely and efficiently. Over time, the convention has undergone significant revisions, including the 1995 amendments and the 2010 Manila Amendments, which aimed to adapt regulations to modern advancements and new challenges within the maritime sector.

This convention does not define whether personnel operating MASS from RCCs qualify as seafarers. This gap means the rules on certification and training would not apply to them. Unlike traditional crew members who must undergo rigorous certification, RCC operators currently fall outside STCW's scope. This creates uncertainty about their qualifications and the training they should be required to obtain. Without a regulatory framework, there is no guarantee that RCC staff are adequately prepared to manage the complex tasks involved in MASS oversight (MSC.1-Circ.1638).⁴⁹

Another key challenge relates to watchkeeping and emergency response, which are central elements of STCW compliance. The convention requires trained personnel to be physically present on board to monitor navigation and respond to emergencies. In the case of MASS, however, these duties are performed by AI-driven systems, raising the question of who assumes ultimate responsibility for safety. Since STCW does not currently account for AI-based decision-making, there is a clear gap in defining legal responsibility when autonomous systems fail to detect hazards or respond to incidents.

⁴⁹ IMO, MSC.1/Circ.1638, Op. Cit.

Moreover, STCW does not account for the limitations of AI in interpreting complex maritime situations. The convention currently does not guide how remote operators should interact with AI-driven systems, nor does it establish criteria for when intervention should override an AI's navigational decisions.

Changqing Xu did a study on the applicability of the STCW Convention to MASS and updating ETO's standard of competence (Changqing, 2020)⁵⁰, where it was determined that the STCW needed to adapt and include MASS considerations, as well as provide the other seafarers with information to navigate safely when they might encounter a level 4 MASS.

As it stands, STCW does not provide an adequate legal framework for MASS, leaving major gaps in training, accountability, and safety standards. Without urgent reforms, autonomous ships will continue to operate in a legal gray area, creating uncertainty for regulators, shipowners, and insurers alike. This thesis will argue that while the IMO may modernize STCW to cover training obligations, domestic and port authorities must also impose clear certification requirements for RCC operators. Only by combining international safety protocols with domestic liability rules can MASS operate safely while maintaining high standards of training and oversight.

4. International Convention for the Prevention of Pollution from Ships (MARPOL)

The MARPOL convention was adopted in 1973 and later modified by the 1978 Protocol, forming what is now commonly referred to as MARPOL 73/78. It is the primary international treaty designed to prevent and minimize marine pollution from ships, covering both accidental pollution and that caused by routine operations. Administered by the IMO,

⁵⁰ Changqing Xu, **Study on the applicability of STCW Convention to MASS and updating ETO's standard of competence**, World Maritime University Dissertations for the Award of Masters in Science in Maritime Affairs Degree. Sweden, World Maritime University, WMO. Sept. 2020. (pp. 3, 36)

MARPOL has been continuously amended to address new environmental concerns and emerging technologies.⁵¹

MARPOL consists of six annexes, each targeting specific sources of marine pollution. Two of those annexes are mandatory for all signatory states, being oil and noxious liquid substances in bulk. These annexes establish strict rules for waste disposal, emissions, and fuel content standards, ensuring that maritime activities comply with global environmental objectives.

The introduction of MASS raises significant regulatory concerns under MARPOL, as the convention was designed for crewed vessels, with compliance mechanisms that assume oversight and intervention. The shift towards Level 3 (remotely controlled) and Level 4 (fully autonomous) MASS presents several critical challenges:

One of the primary concerns is how autonomous ships will comply with MARPOL's pollution prevention protocols, which rely on onboard monitoring, maintenance, and immediate crew response. Tasks such as oil discharge monitoring, leak detection, and emergency inspections are traditionally performed by trained seafarers. Without them, MASS must depend on AI-driven systems, raising doubts about their reliability in preventing or responding to pollution incidents.

As MASS technology advances, MARPOL must evolve to address the challenges posed by uncrewed vessels. The convention, in its current form, assumes oversight and emergency intervention, leaving gaps in accountability. Without updates, MASS could operate in a legal void, making environmental enforcement increasingly difficult. While the IMO may revise MARPOL's technical provisions, effective liability rules will need to be established at the domestic and port level. Port authorities, in particular, will become critical enforcers of pollution prevention by conditioning port entry on compliance with monitoring standards, insurance for environmental risks, and liability allocation for RCCs and technology providers. This dual approach would ensure that MASS remains environmentally

⁵¹ **International Convention for the Prevention of Pollution from Ships (MARPOL)**. IMO, London 1973. Available online: < <https://www.imo.org/en/knowledgecentre/conferencesmeetings/pages/marpol.aspx>>. (Consult: July 10, 2025)

compliant and legally accountable, without undermining global efforts to protect the marine environment.⁵²

B. NATIONAL CASE STUDY: MEXICO AS AN ILLUSTRATION OF THE GLOBAL REGULATORY GAP

The challenges posed by MASS are greater than just AI venturing into the maritime world; the regulatory gap is an international problem that can also be showcased at a national level, especially in countries that are signatories to the core conventions administered by the IMO. For example, Mexico, a coastal nation with a large volume of maritime activity and strategic positioning, serves to illustrate how the absence of comprehensive international regulation on MASS translates into regulatory uncertainty at the domestic level.

Mexico illustrates how the absence of domestic adaptation creates regulatory uncertainty. While the country has incorporated IMO conventions into its legal system, its liability framework remains tied to crew-based navigation, leaving MASS operations unregulated. This highlights why States, rather than the IMO, must lead in reforming liability rules.

Mexico has designed several governmental institutions with regulatory and administrative powers to implement and enforce these international norms. Among them are the Secretaría de Marina (SEMAR), which oversees maritime security and national defense at sea; the Dirección General de Marina Mercante, responsible for the regulation of commercial shipping and merchant marine services; and the Capitanías de Puerto, which operates at the local level to monitor vessel entry and exit, carry out inspections, and uphold maritime safety and environmental protocols. These bodies are tasked with issuing certifications of seaworthiness and seafarer licenses, authorizing ship registrations, and enforcing pollution controls and safety compliance across national ports and waters.⁵³

⁵² International Convention for the Prevention of Pollution from Ships (MARPOL), Op. Cit.

⁵³ Gobierno de México. “*Leyes y Reglamentos SEMAR*” April 12, 2016. Available online: **GOBMX** <<https://www.gob.mx/semar/documentos/leyes-y-reglamentos-27612>>. (Consult: July 10, 2025)

Beyond the application of international law, Mexico has its domestic legislative framework to govern maritime activities. The most comprehensive of these is the Maritime Navigation and Commerce Law (LNCM), first enacted in 2006 and amended on several occasions, with the most recent update in 2020. This law covers a broad range of issues such as the legal regime of vessels, registration, navigational rights, commercial shipping contracts, liability for maritime incidents, and the responsibilities of the ship's captain and crew. It serves as the primary statute governing maritime operations in national waters, complementing international treaty obligations.

However, the LNCM is based entirely on the traditional model of maritime navigation involving human-operated vessels. Its structure and provisions rest on the assumption that all vessels are commanded by a captain physically present onboard, with full authority and responsibility for decision-making during the voyage. This particular issue is presented in Article 27, second paragraph of the LNCM:

“Artículo 27.- ... El capitán de la embarcación será a bordo la primera autoridad. Toda persona a bordo estará bajo su mando, y en aguas extranjeras y en alta mar será considerado representante de las autoridades mexicanas y del propietario o naviero, debiendo tener la capacidad legal y técnica para ejercer el mando de las embarcaciones o artefactos navales y será responsable de éstas, de su tripulación, pasajeros, cargamento y de los actos jurídicos que realice, aún cuando no se encuentre a bordo.” (Original spanish version) ⁵⁴

“Article 27.- ... The captain of the vessel shall be the highest authority on board. Every person on board shall be under his command, and in foreign waters and on the high seas, he shall be considered the representative of the Mexican authorities and of the shipowner or carrier. He must have the legal and technical capacity to command the vessel or naval artifact and shall be responsible for them, their crew, passengers, cargo, and the legal acts he performs, even when he is not on board.” (LNCM, art.27. English version)

The law assigns liability, mandates duties, and defines roles within this conventional framework. This becomes problematic in the context of MASS, particularly those falling within Level 3 and Level 4 categories, which may operate without any crew onboard or with significantly reduced supervision. The LNCM contains no definitions or classifications of

⁵⁴ Ley de Navegación y Comercio Marítimos de México. (Promulgada Junio 2006 / Dic. 2020) (Art.27)

autonomous ships, nor does it provide any mechanism for legal recognition of remote operators, AI system developers, or autonomous control centers.

For example, under current Mexican law, the captain is legally responsible for cargo custody, ensuring navigational safety, and implementing emergency response measures. But in an autonomous ship navigated by an artificial intelligence system or controlled remotely from land-based centers, it remains unclear who bears these obligations. The lack of legislative clarity on these points creates an accountability gap and makes it difficult for authorities to assign legal responsibility in the event of a collision, system failure, or environmental incident.

Similar gaps are found in Mexico's application of MARPOL. Although the country enforces the convention through a combination of port state control mechanisms and environmental legislation, such as the General Law of Ecological Equilibrium and Environmental Protection (LGEEPA, for its initials in Spanish), all environmental duties are currently structured around the physical presence of crew capable of operating pollution control equipment, conducting inspections, and managing emergency protocols.⁵⁵ In an autonomous context, these operations would depend on AI systems and automated technologies, which are not yet recognized or regulated under either MARPOL implementation guidelines or Mexican national law. This absence of legal tools to ensure the prevention and remediation of pollution from MASS introduces risks for compliance enforcement and ecological protection.

Training and certification represent another area of deficiency. While Mexico has implemented STCW requirements through SEMAR and recognized maritime institutions, these apply exclusively to seafarers operating on board traditional vessels. There is no national legal framework to certify or regulate individuals working in remote control centers who supervise MASS, nor any established standards for training in areas such as AI system oversight, cybersecurity preparedness, or data management.

⁵⁵ Ley General del Equilibrio Ecológico y la Protección al Ambiente. (Promulgada Enero 1988/ Abril 2024)

As MASS technology advances and international stakeholders push for its integration into commercial fleets, Mexico faces a pressing need to update and harmonize its legal instruments. Without proactive reforms, the country risks falling behind in regulatory preparedness, opening legal loopholes that may compromise safety, accountability, and environmental protection. The absence of specific provisions for autonomous vessels in national law impairs not only enforcement but also the development of domestic policies to guide investment and innovation in the maritime sector.

Therefore, Mexico must undertake a comprehensive review of its maritime legislation. The LNCM should incorporate definitions of autonomous vessels, recognize different levels of autonomy, and allocate responsibilities to new actors such as RCCs, AI system developers, and technology providers. Likewise, liability frameworks must extend beyond shipowners to cover technological failures, supported by compulsory insurance for MASS operations. Finally, because ports act as the natural enforcement points, Capitanías de Puerto could play a decisive role by conditioning access on compliance with these obligations. By contrast, the European Union has already begun experimenting with regulatory initiatives on automation and cybersecurity, providing a useful benchmark for how regional frameworks may evolve more quickly than national regimes.

C. THE EUROPEAN UNION: REGIONAL ADAPTATION AND EMERGING STANDARDS

The European Union (EU) provides a useful counterpoint to Mexico, as it has already begun to experiment with regulatory initiatives addressing automation, digitalization, and cybersecurity in the maritime sector. While there is no comprehensive EU legal framework specifically tailored to MASS, regional institutions have been more proactive than many individual States in adapting existing instruments and developing forward-looking strategies.

The EU's regulatory engagement with MASS can be traced through several initiatives. The European Maritime Safety Agency (EMSA) has coordinated pilot projects on autonomous shipping, focusing on safety, cybersecurity, and integration with port operations.

EMSA has also issued guidance on risk assessments for automated navigation, highlighting the need for harmonized safety protocols across Member States (EMSA, 2021).⁵⁶ In parallel, the Horizon 2020 program has funded research projects such as AUTOSHIP, which test autonomous vessels under real-world conditions in European waters, generating valuable data for future regulation.

Cybersecurity has emerged as a particular priority. The EU adopted the NIS2 Directive (2022) on network and information security, which applies to critical transport infrastructure, including ports.⁵⁷

This directive requires Member States to impose stricter cybersecurity requirements on operators of essential services, directly affecting ports and shipping companies. By integrating cybersecurity into maritime governance at an early stage, the EU has positioned itself ahead of other jurisdictions in addressing one of the most pressing risks of MASS deployment.

Another relevant area is port adaptation. Under the EU Port Services Regulation (2017)⁵⁸ and subsequent initiatives on smart ports, Member States are required to improve interoperability, digital monitoring, and efficiency in port operations. These measures, although not designed exclusively for MASS, provide a foundation for regulating autonomous vessels' access to EU ports. Port authorities are increasingly recognized as frontline actors, with the power to enforce safety, environmental, and cybersecurity obligations before granting access to MASS.

Despite this progress, the EU framework remains fragmented. There is still no binding regional instrument defining MASS, RCCs, or the liability of technology providers. Member

⁵⁶ European Union. "European Maritime Safety Agency (EMSA)" 2021. Available online: EU < https://european-union.europa.eu/institutions-law-budget/institutions-and-bodies/search-all-eu-institutions-and-bodies/european-maritime-safety-agency-emsa_en>. (Consult: July 10, 2025)

⁵⁷ European Union. "Directive EU 2022-2555 of the European Parliament and of the Council of 14 December 2022 on Measures for a High Common Level of Cybersecurity Across the Union". Available online: EU < <https://eur-lex.europa.eu/eli/dir/2022/2555/oj/eng>>. (Consult: July 10, 2025)

⁵⁸ European Union. Port Services Regulation. 2017 Available online: EU < <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02017R0352-20200528>>. (Consult: July 10, 2025)

States retain discretion to implement EMSA recommendations, leading to uneven application across jurisdictions. Nonetheless, the EU's proactive stance illustrates how regional frameworks can move faster than global negotiations within the IMO, providing practical solutions for emerging risks while maintaining legal certainty for industry stakeholders.

The EU's approach highlights two lessons for the development of MASS regulation. First, cybersecurity, digitalization, and port integration are central elements that cannot be left as secondary concerns. Second, regional cooperation can generate regulatory momentum even in the absence of binding international conventions. In this sense, while Mexico illustrates the risks of legal stagnation, the EU demonstrates the potential of regional adaptation to provide interim governance solutions and prepare the ground for eventual international harmonization.

The following table summarizes the main contrasts identified in the preceding analysis.

Aspect	Mexico (LNCM & Institutions)	European Union (Regional Initiatives)
Legal Framework	LNCM (2006, amended 2020) assumes human crew, captain, and shipowner as main liability actors. No definitions for MASS, RCCs, or AI developers.	No binding MASS convention, but EMSA guidelines, Horizon 2020 projects, and soft-law instruments addressing autonomous shipping.
Port Adaptation	Capitanías de Puerto enforce safety but lack tools for MASS. Entry rules for autonomous ships undefined.	EU Port Services Regulation and smart port initiatives emphasize digitalization and cybersecurity, enabling ports to set MASS entry conditions.

Cybersecurity	No specific MASS cybersecurity provisions.	NIS2 Directive (2022) imposes cybersecurity duties on ports and shipping operators.
Liability	Traditional fault-based model, excluding RCCs and developers.	Liability still fragmented but debates increasingly include RCCs and technology providers.

*Table 5. Mexico vs European Union Approaches to MASS Regulation*⁵⁹

⁵⁹ Table 5. Mexico vs European Union Approaches to MASS Regulation, own work

Chapter III

LIABILITY AND RESPONSIBILITY

Autonomous navigation challenges everything we used to know about maritime law. Liability, traditionally grounded in the fault of the master or crew, now faces new complexities as decision-making migrates from crew onboard to algorithms, remote operators, and manufacturers. The centuries-old assumption that responsibility could be traced to a shipowner's negligence or to the concept of seaworthiness is strained when machines make decisions beyond supervision. Courts may continue to apply existing doctrines such as seaworthiness through judicial interpretation, but such case-by-case adaptation will remain fragmented unless supported by comprehensive legislative reform at the national or regional level.

When MASS comes into play, the clear lines of liability and responsibility become blurry. In the traditional model, claims rested on identifying human error (negligence of the master, crew, or shipowner). By contrast, when a vessel is operated through remote monitoring or relies heavily on artificial intelligence, the potential sources of fault expand to include software designers, system operators, and independent contractors supervising fleets of ships. The dispersal of responsibility makes it increasingly difficult to establish who, in law, should bear the consequences of a casualty. This uncertainty also undermines the ability of insurers to underwrite MASS operations, since risk cannot be allocated without clarity on who bears ultimate responsibility.

In practical terms, the shipowner's personal fault may become more difficult to prove, while liability could shift toward the producers of autonomous technologies or shore-based operators. This has profound implications for the applicability of limitation of liability regimes, which have historically been premised on the negligence of an operator. If actors outside the traditional owner-operator framework become central to the causation of harm, it remains uncertain whether they fall within the protective scope of existing conventions or whether States must develop new liability rules through domestic law.

Beyond the technicalities of liability, MASS raises broader ethical and legal questions. Unlike a master, an AI system cannot weigh moral values when faced with competing risks, such as choosing between the safety of cargo and the protection of life in another vessel's distress. This introduces not only legal uncertainty but also a broader question: should responsibility be distributed solely on economic efficiency grounds, or should it reflect deeper notions of justice, foreseeability, and fairness?

This chapter, therefore, proceeds in two directions. First, it considers how liability must be redefined in the age of autonomous ships, including the possible redistribution of responsibility among shipowners, operators, insurers, and technology providers, with a focus on how domestic and regional reforms can embed product liability principles into maritime law. Second, it explores the ethical and legal challenges of AI decision-making at sea, focusing on accountability gaps and the standards that ought to govern machine-driven choices. Together, these inquiries move beyond existing rules to consider how maritime responsibility can adapt to a world where ships act without a master on deck, and where the task of reform must fall primarily to States and regional organizations rather than to the IMO.

A. MASS AS PRODUCT LIABILITY.

As the crew and shipmaster element withdraws from ship operations, liability must increasingly be reconceptualized through the lens of product liability. An autonomous vessel is not merely a means of transport under the command of a master but a complex technological product that performs critical functions independently. When navigation, collision avoidance, and cargo management are entrusted to algorithms and automated hardware, the risks arising from malfunction or defect are more akin to those in the field of advanced machinery or aviation systems than to traditional seafaring negligence.

This reconceptualization of liability also reshapes the very notion of seaworthiness. Traditionally, the duty of seaworthiness required shipowners to ensure a competent crew and a vessel fit for service. Under MASS, however, the guarantee of seaworthiness no longer rests primarily on the master's judgment or the crew's vigilance, but on the reliability of

software, sensors, and autonomous systems. As Sharma notes, “*the core guarantee of seaworthiness in the age of MASS is technological, not human,*” which shifts the burden from shipowners to manufacturers who are best positioned to ensure that the vessel’s systems are fit for their intended purpose (Sharma, 2019).⁶⁰ This technological dimension of seaworthiness underscores why manufacturers must bear a central role in liability allocation. Courts may still apply seaworthiness through case-by-case reasoning, but such incremental adaptation risks fragmentation, reinforcing the need for explicit domestic reform.

Under such regimes, responsibility attaches to the producers, designers, and distributors of a product when defects in design, manufacturing, or warning cause harm. Transposed to the maritime sphere, this would mean that shipbuilders, software developers, and system integrators could be held accountable if an autonomous vessel fails due to defective programming, inadequate testing, or foreseeable hazards that were not properly mitigated. This approach recognizes that in the MASS context, causation often lies in technical faults rather than misjudgment.

For national legislatures, this shift implies a deliberate extension of existing product liability regimes to cover MASS. Many States already regulate product liability in sectors such as aviation, pharmaceuticals, and automotive technology, where complex machinery operates with high risk to life. Extending these frameworks to autonomous vessels would ensure consistency across legal systems and avoid the creation of parallel maritime-only standards that might complicate enforcement. For example, the European Union’s Product Liability Directive already imposes strict liability on producers for defective products regardless of negligence, while the United States has long relied on tort-based product liability regimes to allocate responsibility for defective vehicles and medical devices. Applying such models to MASS would harmonize maritime liability with established approaches to other high-risk technologies.

⁶⁰ Sharma A.V. Raghav. Op. Cit., p. 39

Victims of MASS-related accidents may face difficulties pursuing claims against manufacturers located abroad or against insolvent developers. For this reason, product liability regimes must be complemented by compulsory insurance or compensation funds. Domestic law can require shipowners, operators, or manufacturers to carry insurance that specifically covers technological defects in MASS, ensuring that injured parties receive compensation even when liability is disputed. This approach not only reinforces victim protection but also incentivizes insurers to demand higher safety and cybersecurity standards from technology providers, thereby embedding private regulatory pressure into the system.⁶¹

Port authorities can also play a decisive role in operationalizing product liability. Because ports serve as natural enforcement points, States can condition entry to national waters or terminals on proof of product insurance, certification of MASS systems, or compliance with safety standards. In practice, this would mean that even in the absence of international consensus, individual States or regional blocs could ensure that MASS operating in their jurisdictions remain insurable, safe, and accountable. This reflects the broader shift in MASS governance: while the IMO may set minimum technical standards, it will be for national and regional authorities to embed liability frameworks into their domestic legal systems.

Ultimately, the conceptual shift from negligence-based liability to product liability provides the most coherent response to the realities of MASS. By allocating responsibility to the actors best positioned to prevent technological failures (manufacturers, software developers, and integrators), States can align liability with control, preserve victim compensation, and promote safety. This section, therefore, lays the foundation for the regulatory proposals that follow, which advocate for the adaptation of domestic laws, the integration of compulsory insurance, and the empowerment of ports as key enforcement actors in the age of autonomous navigation.

B. BLENDED LIABILITY MODELS

⁶¹ Sharma A.V. Raghav. Op. Cit.

Instead of forcing courts to stretch negligence doctrines to cover algorithmic errors, a strict liability model (where liability arises from the defect itself) would provide greater certainty for victims and insurers alike. At the national level, adopting such a model could also ensure more consistent standards of safety across manufacturers, as liability pressures would incentivize rigorous testing, certification, and ongoing monitoring of autonomous technologies. By embedding these obligations in domestic statutes, states can align MASS liability with broader public policy goals such as consumer protection and environmental safety.

Moreover, conceiving MASS as products shifts the distribution of risk in a way that reflects economic realities. Shipowners may still bear operational duties, but the entities best positioned to prevent defects (the technology developers and manufacturers) would shoulder primary liability. This redistribution aligns with broader principles of fairness, as it holds accountable those who profit from introducing autonomous systems into maritime trade while safeguarding claimants' right to compensation.

Sharma proposes that the evolution of MASS liability will require a “blended liability model,” in which shipowners and manufacturers share responsibility in proportion to the risks under their control. This approach can be operationalized through domestic reform: legislators could allocate liability explicitly in statutes (for instance, attributing technological failures to manufacturers and operational breaches to shipowners), thereby reducing the interpretive burden on courts.

Shipowners would continue to bear operational duties (such as compliance with voyage orders and contractual obligations) while manufacturers, who control the integrity of algorithms, sensors, and system design, would shoulder liability for technological failures. This allocation reflects the economic and practical reality that defects in autonomous technologies cannot reasonably be prevented by shipowners, and therefore, responsibility must attach to those entities with the technical capacity to avoid them (Sharma, 2019).⁶²

⁶² Sharma A.V. Raghav. *Op. Cit.*, pp 41, 42.

A key complication arises in collision cases where liability is traditionally apportioned according to the causative potency and blameworthiness of each vessel. While causative potency can still be measured objectively (such as whether a MASS executed a maneuver that contributed to the collision), the assessment of blameworthiness becomes problematic when the “decision” was generated by an algorithm rather than a human actor (Buch, 2023)⁶³. This highlights a fundamental mismatch between fault-based doctrines and autonomous technology: courts cannot attribute moral culpability to software in a meaningful way.

From a product liability perspective, this difficulty is resolved by shifting the focus from blameworthiness to defectiveness. The central question becomes whether the MASS, as a product, met the standard of safety that the public is entitled to expect. If a collision results from defective coding, inadequate sensor calibration, or insufficient cybersecurity safeguards, then liability would attach to the producer or integrator of the system rather than to the shipowner alone. In this sense, product liability not only simplifies adjudication but also ensures that responsibility lies with the parties best positioned to prevent harm through design, testing, and maintenance.

These concerns extend to contractual assurances such as seaworthiness and bills of lading. Maritime trade has long relied on the master’s signature as a guarantee of safe carriage and the proper condition of the cargo. In the MASS context, this assurance disappears, since there is no master onboard to verify and certify. As Buch notes, cargo interests may be left with only raw operational data in the event of a loss, making it difficult to argue whether the vessel was unseaworthy or whether negligence occurred (Buch, 2023)⁶⁴. Here again, this type of liability offers a clearer pathway: instead of debating compliance with human-centric

⁶³ Buch, Harsh.B. **Challenges in Application of COLREGS to Marine Autonomous Surface Ships: The Conundrum: Efficient Applicability & Lack of Jurisprudence on Fault Liability & Dispute Resolution in Maritime Autonomous Operations Giving Rise to Revisit Principles of Appointment of Liability**. Dissertation submitted to the World Maritime University in partial fulfillment of the requirements for the award of the degree of Master of Laws (LL.M.) in International Maritime Law. World Maritime University. 2023 (pp. 62–65).

⁶⁴ Loc. Cit.

notions of seaworthiness, courts could determine whether the vessel, as a technological product, was fit for its intended purpose.

National reforms are therefore crucial: without domestic legislation explicitly redistributing liability, courts will remain bound by fault-based doctrines ill-suited for autonomous operations. By reframing legal responsibility around defectiveness rather than fault, the law can adapt to the realities of unmanned operations while safeguarding cargo owners, third parties, and the environment. This would also incentivize manufacturers and software developers to prioritize safety in system design, while shipowners could negotiate contractual allocations of liability to ensure that risks are fairly distributed across the supply chain.

C. COMPARATIVE INTERNATIONAL APPROACHES

In Mexico, liability for maritime operations is still framed through the Maritime Navigation and Commerce Law (LNCM), which places primary responsibility on the “naviero” and the “operador” for the safe management and exploitation of vessels. The “naviero” is defined as the party that equips, provisions, and maintains a vessel, assuming responsibility for its operation, while the “operador” is the person or entity that, without being the owner or “naviero,” contracts for the use of the vessel or its spaces in their own name⁶⁵. These provisions reflect the traditional assumption that liability arises from human-led control of the ship, whether through direct ownership or contractual operation.

In the case of MASS, however, this liability structure becomes problematic. Autonomous navigation shifts the source of risk from fault to technological performance, and critical decisions may stem not from the “naviero” or “operador” but from a software developer, a system integrator, or a remote-control center. These actors do not fall within the

⁶⁵ Ley de Navegación y Comercio Marítimos. Op, Cit. Art. 2, fracc. IX-X.

statutory categories of liability under the LNCM, leaving significant accountability gaps when autonomous vessels are involved in incidents.

By recognizing autonomous vessels as complex products, Mexican law could extend liability beyond shipowners and operators to include designers, manufacturers, and system providers. In practice, this would mean that shipowners and operators continue to bear operational duties, while technology providers would be directly accountable when harm results from defective programming, inadequate testing, or foreseeable hazards. Such an approach would harmonize the LNCM with the technological realities of MASS, ensuring that liability reflects both operational and technological dimensions of modern shipping.

Although not in force, the Rotterdam Rules provide a useful comparative framework. They envisage a broader conception of liability, recognizing the role of “performing parties,” entities other than the carrier that contribute to the carriage of goods and who may be held jointly and severally liable for damage (Rotterdam Rules, Art. 20)⁶⁶. While these provisions remain largely theoretical and are unlikely to enter into force in the foreseeable future (Jensen, private communication, 2025), they offer valuable insight into how liability could be distributed among multiple actors. For States, the key lesson is that liability regimes must evolve beyond the narrow shipowner–operator framework, explicitly accounting for technological actors who play a decisive role in MASS operations.

“Article 20.- Joint and several liability

- 1. If the carrier and one or more maritime performing parties are liable for the loss of, damage to, or delay in delivery of the goods, their liability is joint and several but only up to the limits provided for under this Convention. “ (Rotterdam Rules. Art. 20)*

This comparative lens highlights the urgency of national reform. While the Rotterdam Rules illustrate a conceptual pathway, States cannot wait for international consensus to materialize. Instead, domestic frameworks must be adapted now. For Mexico, this means amending the

⁶⁶ **United Nations Convention on Contracts for the International Carriage of Goods Wholly or Partly by Sea, 2008.** UN. adopted in Rotterdam on 11 December 2008.

LNCM to recognize MASS as products, assigning liability to manufacturers and system providers alongside traditional actors, and empowering ports and RCCs as the immediate points of enforcement. Ports, in particular, can condition access on compliance with certification, insurance, and liability requirements, ensuring accountability even in the absence of international harmonization (Sharma, 2019).⁶⁷

In this way, this model of liability does not merely supplement existing rules but transforms them into a model that is practical for domestic application. States like Mexico (and regional blocs such as the European Union) can act as laboratories for reform, embedding liability for technological actors directly into their national frameworks. Such reforms would reduce uncertainty for insurers, cargo interests, and shipowners, while ensuring that MASS operations remain safe, accountable, and aligned with the broader objectives of maritime law.

D. THE NEED FOR A UNIFORM INTERNATIONAL LIABILITY FRAMEWORK

The analysis of MASS liability reveals a fundamental truth: the existing system of international maritime law is ill-prepared to address the realities of autonomous shipping. Seaworthiness obligations designed for masters, vicarious liability premised on agency, and doctrines of negligence tailored to human error all falter when the decision-maker is an algorithm.

The result is an increasingly fragmented liability landscape. Some jurisdictions may extend liability to manufacturers through national product liability regimes, while others may hold shipowners responsible despite their lack of control over technological systems. Such divergence would inevitably lead to legal uncertainty, inconsistent compensation for victims, and forum shopping by claimants and defendants alike. In a domain as dependent on

⁶⁷ Sharma A.V. Raghav. Op. Cit., pp 40-44.

uniformity as international shipping, this fragmentation threatens to undermine both efficiency and confidence in MASS operations.

To address this, Sharma proposes that the International Maritime Organization should provide a guiding framework for autonomous vessels, but effective liability adaptation must primarily be implemented at the state level through national legislation, port authorities, and RCC oversight (Sharma, 2019).⁶⁸ Such a framework should rest on three pillars. First, recognition of MASS systems as “products” for liability, ensuring that defects in design, programming, or integration trigger strict liability on manufacturers. Second, adoption of a blended liability model, whereby shipowners retain operational duties, but manufacturers assume primary responsibility for technological integrity, reflecting both fairness and economic efficiency. Third, the establishment of insurance or compensation mechanisms at the international level to guarantee victims’ right to redress, echoing the approach of existing maritime liability conventions.

The evidentiary difficulties created by the opacity of AI decision-making reinforce the argument for adopting strict liability in MASS operations. When algorithms control navigation, collisions or near-misses may occur without any possibility of reconstructing the system’s “reasoning.” In such cases, requiring claimants to prove negligence becomes unworkable. The Comité Maritime International has emphasized that this “black box” quality of AI necessitates a shift away from traditional fault-based liability toward models of strict liability, or at least a reversal of the burden of proof, obliging the owner or manufacturer to demonstrate that the harm was not caused by their system.⁵

Maritime law is not unfamiliar with such approaches: the CLC Convention and the Athens Convention already impose strict liability on shipowners in certain contexts, combined with limitation rights to balance commercial viability. Extending a similar framework to MASS would ensure that victims are compensated even when causation cannot

⁶⁸ Sharma A.V. Raghav. Op. Cit., pp 52-54.

be traced to error, while at the same time incentivizing manufacturers and operators to adopt the highest safety standards.⁶⁹

As Buch observes, the attribution of “blameworthiness” becomes problematic when the operative decision is generated by an algorithm rather than a navigator, making defectiveness a more workable benchmark than fault.⁶ Carey similarly notes that limitation of liability regimes may fail to encompass AI developers or remote-control centers, raising the question of whether new strict liability rules must be crafted to keep MASS insurable and commercially viable (Buch, 2023).⁷⁰

The creation of a uniform liability regime under the IMO would achieve two crucial goals: doctrinal clarity and global harmonization. It would replace fragmented national approaches with a coherent framework, reduce uncertainty for courts and litigants, and ensure that liability aligns with the actors best positioned to manage risk. Most importantly, it would safeguard the legitimacy of MASS within the *lex maritima*, enabling technological innovation without sacrificing predictability in international trade.

While a uniform international framework remains desirable, the persistence of fragmented national approaches makes it clear that ports and states are the immediate regulators. By conditioning access on compliance with liability and safety obligations, states can operationalize MASS regulation more effectively than waiting for a global consensus.

The foregoing analysis demonstrates that liability for MASS cannot be left to the piecemeal evolution of national laws or the reinterpretation of outdated doctrines. Without an international response, the legal vacuum surrounding autonomous technologies risks creating uncertainty, inefficiency, and unequal access to remedies. It is precisely at this juncture that States, supported by IMO guidelines, must intervene. Liability cannot be left to

⁶⁹ Comité Maritime International, “*Navigating a Path Through Liability Issues*” July 2023. Available online: **CMI** < <https://comitemaritime.org/work/mass/>>. (Consult: August 20, 2025)

⁷⁰ Buch, Harsh.B. Op. Cit., pp. 62–63.

international scoping exercises alone; it must be translated into enforceable domestic legislation and port standards.

The next chapter sets out a proposal for how the IMO and States can adapt existing instruments, or create new ones, to regulate autonomy at sea. This proposal aims not only to close liability gaps but also to ensure that MASS operations are integrated into the international legal order in a manner that promotes safety, predictability, and fairness.

Chapter IV

PROPOSAL FOR REGULATIONS AND STATE ADAPTATION TO MASS

A central aspect of this thesis is that liability MASS cannot be expected to be regulated by the IMO. As Dr. Henning Jessen has emphasized in private correspondence, *“The IMO’s mandate is to set out technical and operational standards of due diligence, but not to establish liability regimes.”* (Jessen, 2025).⁷¹ Accordingly, the responsibility for attributing negligence, product defects, or standards of care rests with domestic and regional legal systems.

While the IMO recognizes four levels of autonomy, the proposals developed in this chapter are tailored primarily to Levels 3 and 4, where MASS operates without any crew on board. These stages raise the most urgent legal and regulatory questions, as liability and safety obligations can no longer be satisfied by human presence but must be reframed around product liability, RCC oversight, and technological seaworthiness. Levels 1 and 2 are acknowledged as transitional, but their legal implications remain largely governed by existing frameworks.⁷²

In this respect, ports represent a particularly relevant sphere for regulatory innovation. Given their function as entry points for international trade and their sovereignty under both UNCLOS and national law, port states are ideally placed to require MASS operators to demonstrate adequate liability coverage as a precondition for entry. A product liability model would therefore not only apply in theory but could be institutionalized at the port level through measures such as:

1. **Mandatory proof of insurance** covering software and hardware failures specific to MASS.
2. **Certification requirements** for autonomous navigation systems, linked to IMO technical standards (MASS Code) but enforced by port authorities.

⁷¹ Jessen Henning, (personal communication, Sept. 1, 2025)

⁷² * For a detailed explanation of the IMO’s four levels of autonomy, see Chapter I, Section A.

3. **Liability allocation mechanisms** ensure that in case of a malfunction during docking, maneuvering, or cargo operations, injured parties can obtain redress without needing to litigate complex questions of fault.

Such measures are consistent with existing port state practices under frameworks like the Paris MoU in Europe and the LNCM in Mexico. By linking access to ports with liability safeguards, states can achieve two goals simultaneously: facilitating the safe integration of MASS into trade while avoiding the uncertainty of waiting for an unlikely international liability convention.

The proposal is structured in three parts. First, it identifies areas where existing international conventions presuppose human agency and therefore leave gaps when applied to MASS. Second, it considers how states and regional blocs can address these gaps through domestic legislation, particularly by incorporating product liability principles and adapting port regulations. Finally, it sets out a model of liability allocation, shifting responsibility toward manufacturers and system developers while maintaining contractual and operational obligations for shipowners and operators.

This approach does not seek to provide a fully drafted convention, nor does it expect the IMO to regulate liability. As Dr. Henning Jessen has noted in private correspondence, the IMO's mandate is limited to technical and operational standards, meaning that liability regimes will inevitably remain within the competence of national and regional systems. The objective here is therefore to outline the key areas where regulation must evolve, and to propose how domestic laws (such as Mexico's LNCM or EU liability frameworks) could integrate product liability into the governance of MASS.⁷³

By doing so, this chapter offers a conceptual framework and practical guidance for legislators and port authorities, ensuring that MASS can be deployed without undermining

⁷³ Jessen Henning, Op. Cit.

safety, environmental protection, or the uniformity of technical standards achieved through the IMO MASS Code.

A. GENERAL GUIDELINES FOR STATE ADAPTATION

The regulation of MASS cannot remain in a legal vacuum until the adoption of new international instruments. States must act proactively, ensuring that their domestic frameworks are capable of governing vessels that increasingly rely on automation, artificial intelligence, and remote oversight. The purpose of this section is to propose concrete guidelines that national legislators and maritime authorities can adopt to bridge the regulatory gap, while aligning their legal systems with the long-term goal of international harmonization.

The rationale behind state adaptation is dual. First, it ensures that national waters remain safe and legally predictable, preventing conflicts of jurisdiction, uncertainty in liability, or insurance gaps that could discourage innovation. Second, by introducing clear rules domestically, States contribute to shaping international practice and influencing future IMO reforms. A well-structured national regime can thus function both as an immediate safeguard and as a building block for broader uniformity.

To this end, this thesis proposes States to adopt a flexible but comprehensive framework that addresses the following key areas: 1) Definitions and scope, 2) Recognition of new liability actors, 3) Seaworthiness reinterpreted, 4) Hybrid liability models, 5) Mandatory insurance, 6) Cybersecurity and data standards, 7) Port state enforcement, and 8) Training and certification of RCC operators.

To move beyond theoretical discussion, it is necessary to illustrate how the principles outlined above could be translated into legal text. The following draft Guideline is presented not as a binding convention but as a model that States may adapt within their domestic legislation. Its purpose is to provide clarity on definitions, recognize new liability actors, and

establish mechanisms for enforcement through insurance, cybersecurity standards, and port state control. By articulating these provisions in the style of statutory articles, this Guideline demonstrates how national frameworks can operationalize the shift toward product liability and ensure accountability in MASS operations, while contributing to the gradual emergence of international consensus.

To provide clarity and precision, the following chart presents a structured comparison between the concepts under discussion and their proposed regulatory formulation. Each chart highlights the importance of the issue at stake and offers draft articles that could serve as a model for national adaptation.

This format allows the proposals to remain both practical and flexible, ensuring that States can tailor them to their domestic frameworks while maintaining coherence with international standards.

Definitions and Scope	
Importance	Proposed Article
States should introduce statutory definitions for “autonomous vessel,” “remote-control center (RCC),” and “levels of autonomy,” drawing on existing IMO categories while tailoring them to domestic enforcement needs. Clear definitions prevent interpretive uncertainty in courts and ensure consistency in contractual and insurance arrangements.	Article 1. Definitions For the purposes of this Guideline: 1. “Autonomous vessel” means a ship capable of operating with varying levels of autonomy, as determined by national legislation and in line with IMO categories. 2. “Remote Control Center (RCC)” means a land-based facility authorized to monitor and operate MASS. 3. “Autonomy level” refers to the degree of human involvement in MASS operations, ranging from decision-support systems to full autonomy. 4. “Technological seaworthiness” means the condition of a vessel’s software, algorithms, sensors, and cybersecurity systems, ensuring their reliability and safety for intended operations.
Recognition of new liability actors	
Importance	Proposed Article

Domestic frameworks must explicitly recognize RCC operators, software developers, and system manufacturers as legal actors capable of bearing liability. This departs from the traditional model where responsibility rested solely on shipmasters and shipowners, and reflects the technological reality of MASS operations.	Article 2. Recognition of Liability Actors. - Liability for harm caused by MASS shall extend, in addition to shipowners, to: 1. RCC operators. 2. Software developers and system integrators; and 3. Manufacturers of hardware and technological components. Liability may be joint to the degree of fault, without prejudice to the right of claimants to seek full compensation. Nothing in this Article shall exclude the application of liability regimes under international conventions, including limitation of liability provisions, provided that such limitation does not deprive claimants of effective remedies.
Seaworthiness Reinterpreted	
Importance	Proposed Article
National laws should reconceptualize the obligation of seaworthiness to include not only the physical condition of the vessel but also the reliability of its software, algorithms, and cybersecurity safeguards. A vessel should be deemed unseaworthy if its critical technological systems are defective, untested, or insecure.	Article 3. Seaworthiness Obligation. - A vessel shall be deemed unseaworthy where its technological systems, including software, algorithms, or cybersecurity safeguards, are defective, inadequately tested, or insufficient to guarantee safe operation.
Hybrid Liability Models	
Importance	Proposed Article
States may adopt blended liability regimes, where shipowners continue to bear responsibility for operational duties (such as voyage planning and contractual obligations), while manufacturers and system providers assume	Article 4. Hybrid Liability Model. - I. Shipowners shall remain responsible for all operational duties traditionally incumbent upon them, including compliance with contractual obligations, voyage orders, maintenance of seaworthiness, and ensuring that adequate insurance coverage is in place.

liability for defects or failures within their control. This ensures that liability attaches to the actors best positioned to prevent harm.	II. Manufacturers, system integrators, and software developers shall bear liability for technological failures within their sphere of control, including defective programming, inadequate testing or verification, cybersecurity vulnerabilities, or design flaws that result in damage. III. Remote-Control Centers (RCC) and shore-based operators shall be liable for failures in monitoring, decision-making, or operational oversight falling within their assigned functions, subject to internationally recognized standards of diligence and care. IV. Where multiple parties contribute to the causation of harm, liability shall be allocated proportionally according to the degree of fault, without prejudice to the right of claimants to pursue joint and several liability. All parties subject to this Article shall maintain mandatory insurance or equivalent financial security to cover their respective liabilities, in accordance with international maritime conventions.
Mandatory Insurance	
Importance	Proposed Article
To safeguard victims' right to compensation, States should establish compulsory insurance mechanisms covering technological failures in MASS. Just as the CLC Convention provides mandatory insurance for oil pollution, similar schemes could guarantee coverage for accidents arising from AI malfunction, cyberattacks, or RCC errors.	Article 5. Compulsory Insurance. - I. All MASS engaged in commercial operations shall maintain compulsory insurance covering risks arising from: a. AI malfunction; b. Cybersecurity breaches; and c. Failures attributable to RCCs. II. Certificates of insurance must be presented upon request by port state authorities.
Cybersecurity and Data Standards	

Importance	Proposed Article
National adaptation should incorporate minimum cybersecurity requirements, ensuring that MASS operators comply with internationally recognized standards for encryption, data protection, and incident reporting. Cybersecurity is not only a technical challenge but a condition for safe navigation.	Article 6. Cybersecurity Standards. - All parties involved in the operation of MASS, including shipowners, Remote-Control Centers (RCC), software developers, and system integrators, shall comply with cybersecurity standards established at the national and international level. I. Minimum requirements shall include, but not be limited to: a. Robust encryption of communications and data; b. Intrusion detection and prevention systems; c. Continuous monitoring, auditing, and incident reporting mechanisms; d. Implementation of secure software development and patch management practices; and e. Mandatory cybersecurity training for personnel with access to MASS systems. II. Cybersecurity obligations shall be aligned with relevant IMO instruments, ISO/IEC standards, and other internationally recognized frameworks to ensure harmonization. Failure to comply with these standards shall constitute a breach of duty, giving rise to liability under the applicable provisions of this Convention and national law.
Port State Enforcement	
Importance	Proposed Article
Since ports act as the primary enforcement points of maritime law, domestic regimes should empower port state authorities to verify MASS compliance before granting access. Certification of autonomy levels, proof of insurance, and	Article 7. Port State Verification. - Port state authorities are empowered to: I. Verify MASS compliance with liability, insurance, and cybersecurity requirements. II. Where a vessel is found to be in violation of such obligations, the Port State may, in a manner consistent with international law and principles of non-

cybersecurity audits could be required as conditions of entry.	discrimination: a. Deny entry into port; b. Detain the vessel until corrective measures are demonstrated; or c. Condition port access upon proof of compliance with the relevant obligations. Port State authorities shall notify the Flag State and, where appropriate, the IMO or other competent international bodies of any serious deficiencies detected, and may cooperate in investigations or enforcement actions. Measures taken under this Article shall not prejudice the right of claimants to pursue liability under this Convention or national law.
Training and Certification of RCC Operators	
Importance	Proposed Article
States must create clear rules for the licensing and certification of RCC personnel, ensuring that operators supervising autonomous vessels possess the technical, legal, and ethical training necessary to respond to emergencies.	Article 8. RCC Certification. - Remote-Control Centers (RCC) and their operators shall obtain national certification, issued by the competent maritime authority, as a prerequisite to supervising or controlling MASS. Certification shall require the demonstration of competence in technical, legal, and ethical domains, including but not limited to: I. Maritime navigation and collision avoidance; II. Operation and oversight of autonomous systems; III. International maritime conventions and liability regimes; IV. Cybersecurity protocols; and V. Emergency response and crisis management. The certification shall be subjected to periodic reassessment, continuing education, and audits to ensure compliance with evolving international standards and guidelines.

	Operation of MASS by non-certified RCCs or operators shall constitute a breach of duty, giving rise to liability under this framework, Conventions and national law.
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*Table 8. Draft Guideline on the Safe and Responsible Integration of MASS*⁷⁴

B. THE ROLE OF PORT STATE CONTROL

Port State Control (PSC) has always functioned as the frontline enforcement mechanism of maritime law. While flag States are primarily responsible for ensuring that vessels under their registry comply with international obligations, practice demonstrates that enforcement is often uneven, especially where flag administrations lack capacity or political will. In contrast, PSC operates at the point of entry, granting States an immediate mechanism to condition access to their ports on compliance with safety, environmental, and liability standards. For MASS, this role becomes even more crucial, as traditional oversight tools (such as crew certification or logbooks) are no longer adequate to verify the reliability of autonomous operations.

Against this background, the following illustrative articles as guidelines for State adaptation are proposed. These provisions are not intended to form a binding international convention at this stage but rather to operate as model rules that States may adopt, adapt, and harmonize within their domestic frameworks in line with existing international obligations under UNCLOS and IMO conventions.

Proposed Article 12. Port State Control over Autonomous Vessels:

Article 12.-Port State authorities shall have the power to inspect autonomous vessels calling at national ports to verify compliance with liability, safety, environmental, and cybersecurity obligations established under national legislation. Such inspections may include verification of technological seaworthiness, system integrity, and the authorization of any Remote Control Center (RCC) responsible for the vessel's operations.

⁷⁴ Table 8. Draft Guideline on the Safe and Responsible Integration of MASS, own work

This article extends the traditional inspection powers of PSC to MASS-specific domains. It recognizes that the adequacy of an autonomous vessel cannot be judged by the presence of certified seafarers but rather by the robustness of its technological systems and RCC oversight. By codifying this authority, States would ensure that MASS are subject to effective verification before entering domestic ports, closing the enforcement gap left by flag States.

Proposed Article 13. Conditions for Port Entry:

Article 13.- No autonomous vessel may enter or operate within the jurisdiction of the State unless it demonstrates valid certification of technological seaworthiness, compulsory insurance covering third-party liability for autonomous operations, and proof of RCC authorization and registration. Failure to comply with these conditions shall entitle the Port State to refuse entry, condition access, or detain the vessel until deficiencies are remedied.

This article clarifies that port entry is conditional rather than automatic. It reflects the sovereign right of coastal States to regulate access to their ports (UNCLOS, Art. 25)⁷⁵, while adapting this power to the MASS context. By conditioning access on certification, insurance, and RCC oversight, the provision ensures that autonomous vessels cannot evade liability or enter domestic waters without adequate safeguards.

Proposed Article 14. Enforcement Measures:

Article 14.- Where inspections reveal that an autonomous vessel fails to comply with liability, safety, or cybersecurity obligations, Port State authorities may detain the vessel, impose corrective measures, or deny access to port facilities. Such enforcement measures shall be proportionate, transparent, and subject to procedural safeguards, including the right of the vessel's operator to seek review under domestic administrative law.

This article reinforces that PSC powers must be coupled with enforceable remedies. Without explicit authority to detain or deny entry, inspections alone would be insufficient to guarantee compliance. At the same time, the provision embeds proportionality and due process to align with international law principles and to avoid protectionist misuse of PSC.

⁷⁵ **United Nations Convention on the Law of the Sea (UNCLOS)**. UN, Nov. 1994. Available online: <https://www.un.org/depts/los/convention_agreements/texts/unclos/unclos_e.pdf>. (art. 25) (consult: August 28).

The regulation of MASS through Port State Control is essential to ensuring that liability, safety, and cybersecurity obligations are not reduced to abstract legal standards but are verifiable in practice. By introducing PSC powers specifically adapted to autonomous operations, States can prevent regulatory arbitrage, ensure technological seaworthiness, and create a uniform threshold of compliance for vessels entering their jurisdiction.

These illustrative articles should be understood as guidelines for State adaptation, rather than prescriptive international rules. Each State would tailor inspection procedures, certification requirements, and enforcement mechanisms to its domestic legal framework, while aligning with broader international obligations. In this way, PSC serves as both a safeguard for national interests and a stepping stone toward eventual harmonization of MASS regulation at the international level.

C. RCCS AS RECOGNIZED LEGAL ACTORS

The emergence of Remote Control Centers (RCCs) fundamentally alters the architecture of maritime governance. Traditionally, liability and responsibility were concentrated on the shipmaster and crew physically present on board. In the MASS context, however, key operational functions (navigation, collision avoidance, and emergency response) are shifted to land-based RCCs. Despite their centrality, RCCs remain legally invisible under existing international instruments, leaving significant uncertainty about their status, authority, and liability.⁷⁶

Recent IMO surveys confirm these difficulties. Several States have reported that permitting RCC operations outside the Flag State's jurisdiction would directly conflict with existing UNCLOS requirements, particularly Articles 91 and 94, which regulate ship nationality and manning obligations. This illustrates how the recognition of RCCs as legal

⁷⁶ International Maritime Organization. “*Global SAR Plan*”. Available online: **IMO** <<https://www.imo.org/en/ourwork/safety/pages/globalsarplan.aspx>> (Consult: Sept. 1, 2025)

actors demands not only technical standards but also structural changes in domestic legislation to reconcile national practice with international law (IMO, 2025).⁷⁷

To address this gap, States must explicitly recognize RCCs as legal actors within their domestic frameworks. Doing so provides clarity both for courts adjudicating liability and for insurers calculating risk exposure. The following illustrative articles are proposed as guidelines for State adaptation, ensuring RCCs are incorporated into national regulation in a way that balances accountability with operational feasibility.

Proposed Article 15. Recognition of RCCs:

Article 15.- Remote-Control Centers (RCCs) shall be recognized as distinct legal entities authorized to monitor and operate MASS within the jurisdiction of the State. RCCs shall be subject to mandatory registration, certification, and continuous oversight by the competent maritime authority, in accordance with Article 8 and applicable international standards. Recognition as an RCC carries with it the assumption of duties under Article 16 and potential liability under Article 17.

This article establishes RCCs as formally recognized entities in law, similar to how classification societies or shipping companies are regulated. By requiring registration and certification, States ensure that only qualified RCCs may operate MASS, reducing the risk of unregulated or unauthorized control over vessels.

Proposed Article 16. Duties of RCCs:

Article 16.- RCCs shall ensure continuous monitoring of MASS under their control, maintain real-time communication with port and coastal authorities, and comply with technological seaworthiness requirements. RCC operators must be adequately trained and certified to perform functions equivalent to shipboard officers, as determined by national legislation.

This provision clarifies the substantive obligations of RCCs. By equating operator training and certification with shipboard standards, the article prevents a dilution of safety requirements. It also reinforces that MASS oversight is not a passive activity but requires

⁷⁷ International Maritime Organization. “Maritime Safety Committee, 110th Session, Agenda item 5: Development of a Goal-Based Instrument for Maritime Autonomous Surface Ships (MASS). Report on a survey on current issues concerning Remote Operation Centers,” April 2025. Available online: IMO <<https://comitemaritime.org/wp-content/uploads/2018/05/Comite-Maritime-International-Report-on-a-Survey-of-Current-Issues-relating-to-Remote-Operation-Centres-dd-09-04-25.pdf>> (Consult: Sept. 1, 2025)

professional competence, ensuring accountability comparable to that of seafarers under STCW.

Proposed Article 17. Liability of RCCs:

Article 17.- Where a casualty, collision, or regulatory violation arises from acts or omissions of a Remote-Control Center (RCC), liability shall attach to the RCC as a legal person, without prejudice to the concurrent liability of shipowners, manufacturers, or other parties involved in MASS operations. Such liability shall be determined in accordance with the Hybrid Liability Model established in Article 4, and shall require compliance with the certification, competence, and standards of care outlined in Article 8.

This article addresses the accountability gap directly and makes reference to the articles proposed in the previous table. By establishing RCC liability, States avoid scenarios where responsibility for autonomous operations is deflected solely onto shipowners or manufacturers. At the same time, the provision acknowledges that liability may be shared among multiple actors, reflecting the complex supply chain underlying MASS operations.

Recognizing RCCs as legal actors is indispensable for constructing a coherent liability framework for MASS. Without explicit regulation, RCCs would remain in a legal vacuum, leaving victims of accidents without clear avenues of redress and undermining the enforceability of safety standards. The illustrative articles proposed here provide a model for States to incorporate RCCs into their national law, clarifying their duties, liabilities, and jurisdictional status.

As with Port State Control, these provisions should be viewed as guidelines for State adaptation, ensuring flexibility across legal systems while promoting consistency in the treatment of RCCs worldwide. Their adoption would mark a decisive step in aligning liability frameworks with the realities of autonomous shipping, bridging the gap between traditional seafaring doctrines and the digitalized future of maritime operations.

D. INSURANCE, SAFETY, AND
CYBERSECURITY OBLIGATIONS

The discussion of liability and obligations in the context of MASS is fundamentally different from traditional maritime law. These responsibilities are no longer directed towards seafarers or masters, but rather towards machines, technological systems, and artificial intelligence. This shift raises pressing questions: how can legal frameworks keep pace with a technology that evolves at unprecedented speed? How can we ensure that rules designed today remain effective five years from now? And how should insurance be structured for a vessel that is, in essence, a highly complex product navigating the seas without a single crew on board?

One way to approach these challenges is through the adoption of regulatory guidelines rather than rigid statutory provisions. Unlike laws that may become obsolete as technology advances, guidelines provide flexible yet enforceable standards that require compliance from all new systems, regardless of the pace of innovation. By establishing minimum benchmarks (particularly in areas such as insurance, safety, and cybersecurity), States can ensure that even the most advanced technologies remain subject to oversight, closing potential loopholes that static legislation might leave open.

Insurance plays a critical role in avoiding international disputes and ensuring compensation in the event of accidents, system failures, or cyberattacks. As MASS shifts liability away from seafarers and toward technological systems, insurers must evaluate not only the risks of collision or cargo damage, but also defects in coding, inadequate programming, or failures in software updates. Regular maintenance, certification of systems, and strict monitoring of technological seaworthiness are essential to minimize malfunctions and ensure that insurance coverage remains viable and predictable.

Cybersecurity and safety obligations are equally indispensable. Unlike conventional piracy, which involves physical threats, autonomous vessels face the added risk of cyber intrusions that can seize control of navigation, reroute vessels, or disable propulsion and communication systems. This creates new forms of theft, environmental hazards, and even geopolitical risks. For this reason, MASS must be subject to mandatory cybersecurity

standards, periodic system audits, and safeguards against unauthorized interference, ensuring they remain resilient against rapidly evolving threats.

At their core, MASS systems and algorithms remain products, and like any product, they may malfunction. This paradox highlights the urgency of establishing strong insurance requirements, rigorous safety protocols, and mandatory cybersecurity obligations. Only through such measures can States and insurers ensure that autonomy at sea does not trade one source of risk for another, but instead enhances the overall resilience of maritime operations.

In that sense, the following articles are proposed as a guideline for national or State regulation:

Regarding insurance requirements:

Article 18.- All Maritime Autonomous Surface Ships (MASS), whether engaged in international or domestic navigation, shall maintain compulsory insurance or other equivalent financial security, adequate to cover damages arising from accidents, system malfunctions, cyber intrusions, environmental harm, or failures of autonomous decision-making, regardless of fault. Such insurance shall be maintained by the shipowner and, where applicable, by Remote-Control Centers (RCC) or other operators, and shall grant claimants a direct right of action against the insurer in accordance with international maritime standards.

This article ensures that compensation is guaranteed, even in cases where liability is complex or causation cannot easily be traced to a single actor. It shifts the focus from blame to assurance of redress, a principle already familiar in conventions such as the CLC.

Regarding the certification of technological seaworthiness:

Article 19.- Autonomous vessels, at any level of autonomy, shall undergo mandatory certification at regular intervals not exceeding one year to verify their technological seaworthiness, including the integrity and reliability of software, algorithms, sensors, remote-control links, and cybersecurity systems, as well as compliance with internationally recognized safety and performance standards.

By extending the traditional concept of seaworthiness to the technological realm, this provision recognizes that product reliability, not human vigilance, is now the foundation of maritime safety.

Regarding cybersecurity standards:

Article 6.- All parties involved in the operation of MASS, including shipowners, Remote-Control Centers (RCC), software developers, and system integrators, shall comply with cybersecurity standards established at the national and international level.

- I. Minimum requirements shall include, but not be limited to:*
 - a. Robust encryption of communications and data;*
 - b. Intrusion detection and prevention systems;*
 - c. Continuous monitoring, auditing, and incident reporting mechanisms;*
 - d. Implementation of secure software development and patch management practices; and*
 - e. Mandatory cybersecurity training for personnel with access to MASS systems.*
- II. Cybersecurity obligations shall be aligned with relevant IMO instruments, ISO/IEC standards, and other internationally recognized frameworks to ensure harmonization.*

Failure to comply with these standards shall constitute a breach of duty, giving rise to liability under the applicable provisions of this Convention and national law.

This article acknowledges that MASS is vulnerable not only to physical risks but also to cyber threats. It mandates preventive measures that adapt as threats evolve, minimizing the risk of hijacking, rerouting, or disabling of vessels.

This section proposes that MASS must be insured, certified, and equipped with robust safety and cybersecurity measures to operate legally under national and international frameworks. These illustrative articles demonstrate how States can adopt guidelines that protect victims, preserve environmental and commercial security, and address the unique risks of technological products at sea. By reframing safety obligations around products, States can reduce uncertainty while ensuring MASS remain insurable, seaworthy, and resilient in the face of both mechanical and cyber threats.

CHAPTER V

IMPLEMENTATIONS AND FUTURE CONSIDERATIONS

The effectiveness of the proposed framework ultimately depends on its successful implementation by States and the readiness of ports to adapt to the demands of autonomous navigation. Guidelines and illustrative provisions, such as those advanced in the previous chapter, must be translated into domestic regulation, tailored to national legal traditions while maintaining consistency with international maritime standards. A central element in this process will be port adaptation: MASS cannot function in isolation, and its safe and efficient operation will require ports equipped with compatible technology, capable of communicating with autonomous vessels, and prepared to enforce inspection and liability rules.

In the initial stages, MASS may only be able to operate along routes that connect States whose ports have undergone such adaptation. This selective access highlights the urgency of modernization, as the economic lifeblood of global trade increasingly depends on autonomous technology. States that fail to update their regulatory and port infrastructures risk exclusion from emerging shipping networks, while those that adapt stand to gain from safer, faster, and more cost-effective maritime transport.

Looking ahead, the rise of MASS carries broader implications that extend beyond liability and safety. Automation will alter patterns of global trade, reshape labor demands in the maritime industry, and increase the importance of cybersecurity and digital infrastructure. The proposals developed in this thesis aim not only to address immediate legal uncertainties but also to provide States with a flexible and forward-looking framework that can evolve with technology.

By doing so, the transition toward autonomy at sea can be managed in a way that preserves legal certainty, enhances global connectivity, and secures the benefits of innovation without undermining safety or accountability.

A. RETURN OF THE YV ATLAS

The YV Atlas was introduced at the beginning of this thesis as a fully autonomous cargo vessel whose collision with the KN Horizon exposed the vulnerabilities of the current maritime legal framework. The absence of onboard crew, the opacity of the vessel's algorithm, and the lack of recognition for RCCs combined to create uncertainty over liability and response. If the proposed guidelines set out in Chapter IV had been in force, the trajectory of the YV Atlas incident would have been fundamentally different.

The first point of intervention would have been Article 1 on Definitions. By explicitly defining “autonomous vessel,” “autonomy levels,” and “technological seaworthiness,” regulators and insurers could have evaluated the YV Atlas's compliance before its voyage. Proposed article:

Article 1. For this Guideline, an “autonomous vessel” means a ship capable of operating with varying levels of autonomy, subject to inspection of its technological seaworthiness before departure.

This would have required the YV Atlas to demonstrate that its systems were reliable and fit for purpose, preventing it from sailing without appropriate certification.

Under current frameworks, the operators at shore had no clear legal mandate. Article 4 on RCC recognition would have filled this gap. Proposed article:

Article 4. Remote Control Centers shall be recognized as legal actors with defined responsibilities for monitoring, intervening, and assuming liability in MASS operations under their control.

In practice, this would have ensured that RCC operators overseeing the YV Atlas had both the authority and the duty to intervene when its software failed to recognize the KN Horizon. Liability for inaction would no longer rest in a vacuum but would be traceable under national law.

Before departure, Article 6 on Port State Control would have required the vessel to pass inspections focusing on cybersecurity and collision-avoidance systems. Proposed article:

Article 6. No MASS shall depart a port without proof of compliance with safety, cybersecurity, and technological seaworthiness standards, subject to inspection by port authorities.

In the case of the YV Atlas, this provision could have identified the defective collision-avoidance algorithm before it entered a high-traffic lane.

Finally, victims of the collision would not have been left to dispute liability among shipowners, software developers, and RCCs. Article 7 on mandatory insurance would have guaranteed swift compensation. Proposed article:

Article 7. All MASS shall maintain compulsory insurance covering accidents, environmental harm, and third-party claims, ensuring victims' right to redress irrespective of fault allocation.

This would have allowed immediate remediation of environmental damage and financial compensation without prolonged litigation.

Through these illustrative articles, the YV Atlas case is transformed from a story of regulatory absence into one of accountability and preparedness. Definitions would have clarified its legal status, RCCs would have borne responsibility, port states would have ensured preventive oversight, and insurance would have guaranteed compensation. Together, these measures show that MASS regulation, if designed as adaptable state guidelines, can prevent accidents while ensuring fairness, safety, and efficiency in global trade.

B. FUTURE CONSIDERATIONS

The regulation of MASS cannot be seen as a one-time exercise. Technology at sea will continue to evolve at a pace that often outstrips the ability of law to respond. For this reason, the proposals advanced in this thesis must be understood as a foundation rather than a final product. States that adopt guidelines for MASS today will need to revisit and refine them regularly, just as SOLAS and MARPOL have been amended to reflect new safety and environmental challenges.

In the near term, autonomous vessels will not replace traditional fleets entirely but will operate alongside them. This coexistence will create complex interactions, particularly in dense sea lanes where judgment and algorithmic decision-making will meet. Regulation must therefore anticipate not only the functioning of MASS in isolation but also their behavior in mixed-traffic environments, ensuring that principles such as good seamanship and collision avoidance remain meaningful. Just as the Maritime Cyprus states: “*For the foreseeable future, we will have a mixed fleet of conventional ships with different degrees of automation in combination with an increasing number of MASS.*” (Maritime Cyprus, 2024).⁷⁸

Another key consideration is the problem of fragmented regulation. If each State develops its own framework in isolation, MASS operators will face a patchwork of inconsistent rules. This could undermine the efficiency and predictability that make autonomy attractive in the first place. Future efforts should therefore prioritize mutual recognition agreements and regional coordination, with the IMO playing a guiding role to ensure that domestic innovation ultimately converges toward shared standards.

MASS may face conflicting priorities (life, cargo, environment). The ethical concern lies in *who codes these priorities* and *whose interests prevail*. Transparency in algorithm design and oversight is essential to avoid biased or profit-driven outcomes.

Cybersecurity will remain one of the most pressing long-term risks. As technology advances, so too will the sophistication of those seeking to exploit it. The threat of digital piracy (seizing control of a vessel remotely or disrupting its systems) will demand continuous adaptation of legal and technical safeguards. States must be prepared not only to impose national cybersecurity standards but also to cooperate internationally in responding to incidents that transcend borders.

The insurance market will also continue to adapt. At present, insurers are only beginning to design products tailored to autonomous operations. Over time, actuarial data on

⁷⁸ Maritime Cyprus. “*The Future of Maritime Autonomous Surface Ships.*” 2024. Available online: <https://maritimecyprus.com/2024/01/15/the-future-of-maritime-autonomous-surface-ships-mass/> (Consult: Sept. 1, 2025)

MASS performance will allow for more accurate risk assessments, which may reduce premiums and encourage broader adoption. This evolution will require regulatory support, particularly through obligations on States and operators to share safety and casualty data transparently.

Finally, MASS raises broader environmental and ethical questions. On one hand, reducing human error has the potential to increase safety at sea and lower the risk of catastrophic pollution, and it makes economies grow as they will save thousands on claims and even payroll for crew on board. On the other hand, entrusting decision-making to algorithms means that errors, when they occur, may be systemic rather than individual. The law must therefore embed principles of precaution, accountability, and fairness to ensure that technological efficiency does not come at the expense of values or environmental protection.⁷⁹

Taken together, these considerations highlight that the regulation of MASS must remain flexible, adaptive, and internationally coordinated. The proposals developed here are intended to provide States with a starting point that balances innovation with accountability. In the decades to come, the success of MASS will depend not only on their technical performance but also on the ability of the law to evolve alongside them, ensuring that autonomy enhances, rather than undermines, the safety and stability of global trade.

The regulation of MASS is no longer a question of if, but how. By shifting liability from seafarers to systems, recognizing RCCs as legal actors, and embedding insurance, safety, and cybersecurity obligations, States can transform uncertainty into accountability. The case of the YV Atlas showed what is at stake if regulation stays behind technology; the proposals advanced in this thesis show how those risks can be managed and prevented.

In addition to the challenges already identified, the future regulation of MASS should incorporate preventive and adaptive measures that extend beyond traditional maritime law. This includes the establishment of compulsory insurance not only for cargo and third-party

⁷⁹ Maritime Cyprus. Op. Cit.

liability, but also for environmental damage, ensuring that owners and operators internalize the risks of pollution or systemic technological failures. Compliance programs tailored to each vessel should be implemented, with policies and internal controls designed to prevent the carriage of prohibited items and to allocate responsibility in the absence of onboard crew. Equally, seaworthiness must evolve into a technological concept, requiring continuous software certifications and the integration of STCW-like training standards focused on digital oversight.

Dispute resolution mechanisms should also prioritize international arbitration, offering efficiency and neutrality in resolving cross-border conflicts where traditional jurisdictional rules may falter. At the same time, piracy prevention must adapt to the digital sphere, mandating surveillance tools and cyber-protective measures that address the unique vulnerabilities of autonomous navigation.

Finally, international conventions should progressively incorporate dedicated chapters on Artificial Intelligence, creating binding obligations that reflect the ethical and operational dilemmas inherent in machine decision-making. Taken together, these developments should converge in international waters under UNCLOS and IMO frameworks, reaffirming the flag State's responsibility while ensuring that MASS are subject to uniform global standards rather than fragmented national approaches.

CONCLUSIONS

This thesis set out to examine the legal, regulatory, and ethical challenges posed by Maritime Autonomous Surface Ships (MASS), and to propose concrete frameworks for their governance at both the international and national levels. From the outset, the fictional case of the YV Atlas was used as a narrative device to illustrate how current conventions collapse when confronted with a fully autonomous vessel. That case highlighted the urgency of adapting maritime law to technological realities.

Chapter I provided an overview of MASS and its growing role in global trade. It explained the different levels of autonomy, from vessels supported by decision assistance systems to fully autonomous ships, and analyzed the implications of these levels for safety, liability, and compliance. This chapter also introduced the main governance issues, such as cybersecurity risks, the emergence of Remote-Control Centers (RCCs), the reliance on artificial intelligence (AI) in decision-making, and the transformation of vessel port communications.

Chapter II turned to the international framework under the International Maritime Organization (IMO). It reviewed the core conventions (UNCLOS, SOLAS, COLREGs, MARPOL, and STCW) and identified the gaps that make them difficult to apply to uncrewed vessels. The analysis showed how these conventions presuppose the presence of human masters and crews, leaving MASS without clear rules on watchkeeping, training, or emergency intervention. The chapter also examined Mexico as a national case study and contrasted it with the European Union's regional approach, thereby illustrating the contrast between domestic and regional innovation.

Chapter III examined liability and responsibility. It argued that traditional negligence-based liability models are inadequate for autonomous operations, since decisions often originate in software, algorithms, or RCC oversight rather than officers. The chapter advanced the view that MASS should be treated under a product liability model, shifting responsibility to manufacturers and system integrators. It also explored blended liability

models and reviewed comparative approaches, including insights from the Rotterdam Rules. The need for a uniform framework was emphasized, while acknowledging that IMO's mandate is limited to technical standards.

Chapter IV presented the core proposals of the thesis. It outlined guidelines for state adaptation, covering definitions, recognition of RCCs as legal actors, reinterpretation of seaworthiness, hybrid liability models, compulsory insurance, cybersecurity standards, port state enforcement, and RCC certification. Draft articles were formulated to illustrate how national legislatures and port authorities could operationalize these principles. This chapter placed particular emphasis on the role of ports as enforcement points, recognizing that market access offers States an effective tool to ensure accountability even in the absence of binding international treaties.

Chapter V revisited the YV Atlas case to demonstrate how the proposed framework could transform uncertainty into accountability. By applying the draft provisions on definitions, RCC recognition, port state inspections, and compulsory insurance, the incident was reframed as one where victims receive compensation, ports ensure compliance, and liability is properly allocated. The chapter then broadened the lens to consider future developments, including the coexistence of conventional and autonomous fleets, the risks of fragmented regulation, the growing role of cybersecurity, the evolution of insurance markets, and the ethical dilemmas inherent in delegating judgment to AI.

The central contribution of this thesis lies in the reconceptualization of liability for Maritime Autonomous Surface Ships as a form of product liability. By reframing MASS as technological products rather than traditional vessels commanded by a master, the thesis demonstrates that accountability must extend beyond shipowners to manufacturers, system integrators, and software developers. This approach introduces a novel perspective into maritime law, aligning it with established liability frameworks already applied in sectors such as aviation, pharmaceuticals, and automotive technology.

A second contribution is the identification and detailed recognition of Remote-Control Centers as legal actors. The thesis argues that RCCs, which assume critical functions of navigation and oversight, can no longer remain invisible in international conventions. By proposing draft provisions for their certification, training, and liability, this research offers a practical solution to one of the most significant accountability gaps in autonomous shipping.

Third, the thesis places port state control at the center of MASS enforcement. Ports are uniquely positioned to verify compliance with insurance, cybersecurity, and seaworthiness standards before granting access. This emphasis on port state powers moves the debate from abstract theory to concrete mechanisms of implementation, showing how States can safeguard accountability even in the absence of binding law.

Another major contribution is the drafting of illustrative statutory provisions. By presenting articles that national legislators could adopt, this thesis goes beyond doctrinal analysis and provides tangible tools for reform. These articles cover definitions, liability allocation, technological seaworthiness, compulsory insurance, and RCC certification, offering a framework that States can adapt to their legal systems.

Finally, the thesis highlights the importance of integrating ethical considerations into the regulation of MASS. By analyzing how artificial intelligence lacks intent, situational awareness, and moral judgment, it underscores the need for legal frameworks that incorporate precautionary and fairness principles. This ethical dimension is rarely developed in maritime scholarship and represents a significant addition to the existing literature.

Taken together, these contributions expand the current debate beyond the recognition of regulatory gaps. They provide new conceptual tools, practical proposals, and ethical insights that can guide States, regional organizations, and the maritime industry toward a coherent governance structure for autonomous navigation.

Beyond the doctrinal and practical contributions, the process of researching and writing this thesis was a profound learning experience. Since the subject of Maritime Law

was not part of my law school curriculum, I had to build my knowledge from the ground up. This required me to learn and relearn concepts from international law, transport law, and liability theory, and to connect them with technological realities that are still in development.

At the beginning, I believed that adapting existing conventions would be a sufficient solution, but after extensive research, I realized that the challenges of autonomy are deeper than expected. This led me to change the scope of the thesis twice, as my initial assumptions proved incomplete. The most significant turning point was the discovery of product liability as a framework to rethink responsibility in autonomous shipping. Recognizing MASS as products rather than only as vessels allowed me to develop a fresh perspective that shaped the central argument of this work.

The research also exposed me to the speed of technological innovation and the gaps that exist between engineering progress and legal adaptation. I was constantly struck by how quickly shipbuilding and automation are evolving, and how slowly law responds in comparison. This realization gave me a sense of urgency about the role lawyers and policymakers must play in ensuring that regulation does not stay behind technology.

The process also raised new questions that go beyond what I could answer in this thesis. For instance, I wonder how the cruise industry will adapt to autonomy, and whether the human element of hospitality and safety at sea might one day be replaced by robots or artificial intelligence. While these ideas may seem futuristic, they are no longer science fiction, and they highlight the need for law to prepare for scenarios that challenge our assumptions about work, safety, and ethics at sea.

Writing this thesis, therefore, taught me as much about myself as it did about the subject matter. It pushed me to think critically, to accept uncertainty, and to adapt when my research took unexpected directions. It showed me the value of perseverance, of questioning assumptions, and of embracing interdisciplinary learning. Most of all, it reminded me that law is not a steady line, but a living system that must constantly evolve in dialogue with society, technology, and the environment.

Although the research reached its objectives, the process was not without challenges and limitations. The first obstacle was the freshness of the subject. MASS is still in an experimental stage, with pilot projects in Norway, Finland, and Japan, but with little practical experience available to analyze. This meant that much of the work relied on academic writings, IMO reports, and comparative studies rather than judicial precedents or consolidated case law. The absence of jurisprudence limited the possibility of grounding arguments in practical decisions and required greater creativity in framing proposals.

A second limitation arose from the lack of specific regulation in Mexico. The Ley de Navegación y Comercio Marítimos does not yet address MASS, and therefore, the analysis of domestic law could only identify gaps rather than offer concrete applications. While this highlighted the urgency for reform, it also meant that some proposals remain at the level of theory until Mexico or other States take legislative action.

Another difficulty was the scope of the research itself. At first, the project aimed to cover both contractual and extra contractual liability in detail, as well as cybersecurity, insurance, port operations, and labor aspects. However, it became clear that such ambition would dilute the analysis. For this reason, the focus was progressively narrowed. The adjustment of scope was necessary, but it also meant leaving aside topics that could have enriched the discussion, such as insurance market adaptation or the labor rights of seafarers in transition.

The rapid evolution of technology also posed a challenge. During the time this thesis was being written, new developments and trials of autonomous vessels were announced, often with features that surpassed what had been discussed in earlier literature. This made it difficult to work with a stable picture of technology, since the subject is in constant transformation. The conclusions are therefore based on the best available information, but they must be read with the awareness that MASS capabilities will continue to change.

This thesis inevitably leaves open questions that merit further study. One of the most pressing is how the principles developed for cargo vessels will apply to the cruise industry.

Cruise ships combine transportation with hospitality, and it remains uncertain whether autonomy could ever replace the role of crew members who are essential not only for safety but also for service. The legal implications of reducing or even replacing human personnel with robots or artificial intelligence would raise complex issues of liability, labor rights, and consumer protection.

Future research should also examine the interaction between autonomy, cybersecurity, and international security law. As MASS becomes more integrated into global trade, it may be vulnerable to cyberattacks or even unlawful purposes such as smuggling or piracy. These scenarios require legal frameworks that combine maritime law, technology regulation, and security law. More broadly, innovation in artificial intelligence and robotics will continue to challenge the traditional assumptions of maritime law, demanding constant adaptation of doctrines that were once thought to be settled.

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